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NASA's SPACE SCIENCE PROGRAMS AND THE MISSION TO PLANET EARTH

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BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

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NASA's SPACE SCIENCE PROGRAMS AND THE MISSION TO PLANET EARTH

WEDNESDAY, APRIL 24, 1991

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY,
AND SPACE OF THE COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:35 a.m. in room SR–253, Russell Senate Office Building, Hon. Al Gore (chairman of the subcommittee) presiding.

Staff members assigned to this hearing: Steve Palmer, senior professional staff member; and Louis Whitsett, minority professional staff member.

OPENING STATEMENT OF SENATOR GORE

Senator GORE. The subcommittee will come to order. I want to welcome our witnesses and guests.

When the Augustine Committee released its findings and recommendations last December, I was among those particularly pleased when it asserted that space science must be NASA's highest priority. As chairman of the Science, Technology, and Space Subcommittee, I enthusiastically endorse that conclusion. I have noted that many others have done so as well.

NASA's space science research is a critical part of our effort to better understand the Earth, the universe, and how we can better live in those environments. NASA says that it also shares this conclusion and points to its ongoing activity in NASA's astrophysics, earth science, life science, planetary exploration, materials science, and communications technology programs. With a fiscal year 1992 budget request for space science and applications programs approaching $3 billion, we are, NASA has repeatedly claimed, in the midst of the second golden age of space science.

Unfortunately, the situation at hand it is not that simple. The budget resolution now being debated on the Senate floor falls short of providing the total amount requested for NASA and the other federally funded science programs. Specifically, the Senate Budget Committee has recommended that the budget for Federal science and space programs be increased by only 6 percent in the coming fiscal year.

It is therefore incumbent upon us today to build a record the subcommittee can use to develop an authorization bill that brings NASA's program priorities and funding levels into balance. Indeed, we must take this course if we are to fulfill the recommendations

of the Augustine Committee to establish NASA's space science programs as the agency's highest priority.

We will attempt to cover a great deal of ground at today's hearing, first reviewing the broad array of space science missions currently in progress, as well as those under development. We will then focus more closely on those programs included in the initiative known as the Mission to Planet Earth.

There are a number of important issues that I hope we will be able to address. First, after the disappointment that came last year with the detection of the Hubble space telescope's spherical aberration, I am very interested in NASA's efforts to develop replacement instruments to overcome this design flaw. It is my hope that we can also learn more about the potential loss of science that may result from the failed deployment of the Galileo spacecraft's main communications antenna while en route to Jupiter.

Finally, in addition to examining these and other key space science missions, I hope to explore related issues of importance, including NASA's data management policies and the possible application of cost containment provisions to future missions.

I would like to digress for a moment to comment on how troubled I have become about the increasing number of problems being encountered during the deployment of many of NASA's spacecraft. Of course, it is natural, given the complexity of the missions that are being attempted, to have problems occur. But we have seen jammed antennas on not only Galileo but the Gamma Ray Observatory, which was successfully deployed earlier this month only after astronaut Jerry Ross was able to literally shake the antenna free during an emergency space walk.

Combined with the problems with Hubble, caused by, of all things, an inverted measuring rod, the scenario causes an alarm of growing proportions. Mistakes that on their face seem relatively simple can become major roadblocks to the success of our Space Science Program.

Much of our hearing today will focus on NASA's Mission to Planet Earth. At the outset, let me say what I have said before, that I very strongly support the objectives of NASA's program. It is imperative that we expeditiously gather data on the Earth's environmental processes. NASA has a key role to play in that effort through the flight of instruments in space, as well as the development of a data information network capable of collecting, archiving, and disseminating research data to scientific users.

There are two simple themes that ought to motivate the development of this program. First, there is the need to collect data on environmental change. Second, that data must serve a purpose. And while these sound simple enough, I would like to use two analogies to help highlight why I believe they are critical to the success of this program.

In 1987, the Montreal protocol was established, requiring developed nations to freeze their chlorofluorocarbon production and consumption, reducing future CFC production levels over the following decade. Then, only 1 year later, in March 1988, data collected by NASA satellites indicated that ozone depletion was occurring two to three times faster than previously recognized. This new information became the key element of last year's worldwide effort to

strengthen the Montreal protocol, requiring the total phaseout of CFC's and other ozone-depleting chemicals.

As we explored at a subcommittee hearing last week, even newer NASA data indicates that during certain times of the year the ozone layer over much of the United States has thinned by twice as much as previously expected. Armed with this new information, I and about 30 other Senators called on the administration to invoke provisions of the Clean Air Act that would accelerate the phaseout of CFC's in this country, and we are calling on the administration to convene a special session of the nations who have signed the Montreal protocol to prompt further international action.

Very simply, none of this could have occurred without the data collected by NASA satellites. Indeed, without that monitoring capability we might never have known that we needed the Montreal protocol in the first place. In developing future environmental monitoring programs, however, it is imperative that we keep in mind why we need them.

Right to the point, the Mission to Planet Earth must be focused on the needs of environmental policymakers. It does no good to the Congress nor to the administration to collect data that is not timely or useful as decisions about the future of our planet are being debated. It is good to collect as much data as we possibly can, but we need decisions in the near term about how to get started in confronting the global environmental crisis.

Again an example may help illustrate what I am trying to say here. In 1980, when acid rain was becoming an issue splitting regional interests in this country, Congress created the National Acid Precipitation Assessment Program. NAPAP, as it came to be known, was intended to marshal the best available science to determine the causes and effects of acid rain and how to control it.

During the next decade, some 2,000 scientists spent more than $500 million studying everything from lake sediments to atmospheric processes, to damage to chain link fences. They built megacomputer modeling programs that were great for the details of science, but were overkill when it came to what was needed to develop public policy.

I have enormous respect for those who participated in and conducted that study, and I have no reason to challenge the actual text of what they reported. But in fact by the time the Congress had concluded action on the Clean Air Act, with its provisions on acid rain, NAPAP was nowhere to be found. We cannot afford that kind of approach with Mission to Planet Earth.

If the policymakers here in the United States and around the world have completed a whole round of decisions and set in motion dramatic changes in order to deal with global climate change, and then 5, 6, 7 years later the information from Mission to Planet Earth finally becomes available, it will not have played the role that we hope here at the outset it can.

We do not have the resources nor the time for Mission to Planet Earth to be a repeat of the NAPAP experience. In order to take the necessary actions to address critical matters such as global warming, we must ensure that this and other research efforts provide

answers to the questions that policymakers have, not merely what may be interested to the research community.

In discussing these issues today we are fortunate to have with us Dr. Len Fisk, NASA's Associate Administrator for Space Science and Applications, as well as a panel of distinguished researchers who I will introduce after Dr. Fisk's testimony, each of whom has made substantial contributions to the field of earth science. They have been invited to provide comment on the manner in which the development of the Mission to Planet Earth, of EOS, of EOSDIS, and the Earth probes is proceeding.

I would like to recognize Senator Hollings.

OPENING STATEMENT OF SENATOR HOLLINGS

The CHAIRMAN. Thank you , Senator Gore.

Today the committee will continue its review of the NASA fiscal year 1992 budget request, focusing on the agency's Space Science Program, with particular emphasis on the Mission to Planet Earth. This hearing will address a wide-ranging set of issues relating to a variety of important space science missions.

In addition to the space science missions currently being developed, the committee has a great interest in the condition and capabilities of the Hubble Space Telescope and the Galileo mission now on it way to Jupiter. Both missions have experienced problems that threaten the ability of scientists to gather the complete data sets that had been envisioned when the missions were first approved by Congress. We must have a complete understanding of these problems and their causes to ensure that these problems do not recur in future NASA missions.

NASA's Mission to Planet Earth, which is an essential element of the U.S. Global Change Research Program, is another important area to be examined during today's hearing. This broad initiative, which is projected to cost close to $17 billion through the end of this decade, is envisioned to include a series of large and small spacecraft capable of gathering data to be archived in a new comprehensive data management system. Once operational, this coordinated program of data collection, storage, and distribution is expected to be an important tool to scientists working to understand our global environmental systems. In turn, that research will help policymakers to take appropriate actions to help improve the Earth's environment.

I welcome the witnesses appearing before the committee today. Their insight is greatly appreciated as the committee proceeds with its fiscal year 1992 NASA authorization bill.

Thank you, Senator Gore.

Senator GORE. Thank you, Mr. Chairman. Before going to our first witness, I would like to recognize Senator Pressler.

OPENING STATEMENT OF SENATOR PRESSLER

Senator PRESSLER. Thank you, Mr. Chairman. I want to thank you for holding this hearing on Mission to Planet Earth and NASA's other space science programs.

I am pleased we have Dr. Fisk here today along with the other witnesses. I had the pleasure to get to know Dr. Fisk a little bit in recent months. In my view, he is one of the preeminent scien-

tists in this field. We are very fortunate to have his talent in Government. In fact, I am always amazed that people like Dr. Fisk consistently sacrifice. I am sure they could easily double or triple their salary in the private sector. We are lucky to have you.

Mr. Chairman, I believe that Mission to Planet Earth is critical to our future. Last week, this subcommittee heard from NASA witnesses who testified that ozone depletion is occurring twice as fast as scientists had thought. They also told us that ozone depletion covers a wider area of our globe and lasts for longer periods of the year than earlier believed. This is troubling news for our planet, since the ozone layer is our main protection against ultraviolet radiation that can cause skin cancer, cataracts, and crop damage.

In addition, tomorrow this committee has a hearing on the equally urgent problem of global warming, which threatens dramatic climate changes around the world.

In this environment, Mission to Planet Earth is the right program at the right time. Mission to Planet Earth will apply NASA's best satellite and computer technology to ozone depletion, global warming, and other global climate threats to humanity. When the first earth-observing system platform is launched in 1999, there will be a tremendous flow of data. In fact, NASA will collect more data in 1 day than it previously collected in 1 year. For this reason, I look forward to hearing what steps NASA is taking to develop the data and information system needed to handle this information flow.

As I have mentioned, I know that Dr. Fisk has been at South Dakota's EROS data center. But I am concerned that NASA has decided to delay by 6 months the request for proposal for the data management system in Mission to Planet Earth. We must not allow the development of the ground-based data system to be delayed.

Mission to Planet Earth will work only if the satellite data is properly collected, archived, and made available for global change researching and modeling. These data issues are a key point, and I hope that NASA makes this matter a high priority.

Mr. Chairman, let me again thank you for holding this hearing. I welcome Dr. Fisk and our other distinguished witnesses to our subcommittee.

Thank you.

Senator GORE. Thank you very much, Senator Pressler.

Dr. Fisk, I have been informed that in a few minutes I will have to contribute to the formation of a quorum down the hall, and I am going to ask Senator Pressler to chair during the portion of your testimony here. I want you to know that no discourtesy is intended when I have to be absent for a part of your testimony.

Your full text will be included in the record, without objection, and we are interested in what you have to present to us this morning. Please proceed.

STATEMENT OF DR. LENNARD A. FISK, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; ACCOMPANIED BY A.V. DIAZ, DEPUTY ASSOCIATE ADMINISTRATOR, KATHRYN S. SCHMOLL, ASSISTANT ASSOCIATE ADMINISTRATOR, AND DR. SHELBY TILFORD, DIRECTOR, EARTH SCIENCE AND APPLICATIONS DIVISION

Dr. FISK. Thank you very much. It is a pleasure to be here, Senator. I have a statement which you have accepted. If you will permit me, I thought what I would do for a few minutes this morning is talk about two things—share some of the recent science results from NASA's missions and then talk just briefly about Mission to Planet Earth as a way of getting into the many questions I am sure you will address.

If you do not mind, I will stand up. The old classroom professor in me cannot talk about slides sitting down.

The basic message I want to leave you is we are having a good time these days. NASA's satellites are producing a phenomenal amount of data, and this literally, I think, can be described as the second golden age of space science. All you have to do is go to science meetings these days. Where a few years ago people were simply analyzing data that was 10, 15 years old, now between each meeting there is a new machine flying and new data coming in.

[A slide was presented.]

Dr. FISK. This is a picture from the Hubble space telescope. Hubble is doing extremely well. We had, you may recall, the hearings here last year. Even the optimism that we expressed on our ability to make Hubble work with the spherical aberration has been exceeded. Hubble is working beyond our expectations.

These pictures are proof of that. This is a picture of the supernova 1987A, the one that went off in the large Magellanic cloud, the closest supernova in the last 100 years. You can see the material ejected from the supernova. This is not possible to see from the ground. It is an observation not only of interest to the supernova but because you can measure the diameter of that. If you know when a supernova occurred and you know how fast the material is expanding, you can in fact get an absolute distance scale to the large Magellanic cloud, which is the first building block in understanding distance scales across the universe.

So, it is measurement of considerable interest to astronomers.

[A slide was presented.]

Dr. FISK. This is a picture again from Hubble of M–14, which is a globular cluster, some of the oldest stars that exist in our galaxy. That is the best you can do from the ground, and that is Hubble. The resolution I think is phenomenal. The spherical aberration in Hubble is a very predictable spherical aberration. If you have an object of sufficient contrast you can use a computer, take the spherical aberration out, and get all the resolution Hubble was intended to do.

Now basically you are limited to objects that are brighter than about 25th magnitude. If you get to objects fainter than that, 25th to 28th magnitude, then the contrast is not good enough to be able to do the spherical aberration correction. But there is a lot of universe out there at the 25th magnitude. The 25th magnitude is all

you could ever see from the ground in any event. But the correction still needs to be made to Hubble to get from 25th to 28th magnitude.

[A slide was presented.]

Dr. FISK. Our own solar system has given us some real surprises with Hubble. This is the storm that occurred on Saturn. You can actually see this kind of detail. Saturn, as the atmosphere erupted, turned into a dramatic storm last fall. You may recall we flew by with Voyager. It was really a very tranquil atmosphere. It suddenly turned into spots and turbulence like on Jupiter, and you can study that in detail with Hubble, again not available from the ground.

[A slide was presented.]

Dr. FISK. Mars. This is a Hubble picture of Mars. You are actually able to track the weather systems on Mars. Again, because Hubble is up all the time, we can take periodic observations of this throughout the Martian seasons and you can actually see the weather patterns evolving on Mars. Again, not available from the ground.

[A slide was presented.]

Dr. FISK. I do not know whether this is going to be visible to you, but you recall that we told you that one of the things we would emphasize in the early days of Hubble was spectroscopy, actually the ability to look at a spectra and see individual lines in the spectra and therefore determine the composition of the objects we were seeing in detail.

This top line is an international ultramonitor source spectrum, with an object called "chi Lupi," which is a very hot star. These spectra are just indications of the kind of material that is there. The Hubble spectra has very many detailed lines showing the individual elements that occur in the star. It is a star of unusual composition, something like 10,000 times the amount of platinum and mercury that is in our Sun

[A slide was presented.]

Dr. FISK. I can also not fail to mention this spectrum may turn out to be one of the most famous spectra in science. This one is taken from COBE, the Cosmic Background Explorer. You remember COBE was looking at radiation from the very beginning of the universe, the big bang. This spectra is of such exquisite smoothness, it is an actual perfect black body spectra. In other words, the material that existed at the very beginning of the universe is without variation, without any inhomogeneity. It is perfectly smooth, uniform temperature material.

That is a great puzzle to cosmologists because the universe we see today is very inhomogeneous. We are obviously all here on little clumps, and there is no known theory that allows you to go from a universe which was so uniform at the beginning to a universe which is so inhomogeneous today.

So, cosmologists are very puzzled about what the formation of the universe is as a result of these COBE measurements.

[A slide was presented.]

Dr. FISK. Magellan is completed with its prime mission phase. We have done 70 percent of the planet, which was our goal for the prime mission, but we will continue on doing that, continue to map as much as 80 or 90 percent of the planet over time. We have reso-

lution here of 400 meters, a factor of 10 better than it has ever been before.

It is a geologist's dream. Basically, Venus is the same size as the Earth, but it has none of the debris on the surface which we call vegetation or dirt or life on the Earth. It is like looking at the bedrock of a planet similar to the Earth without any of this debris in the way. And the geologists can study about how a planet the size of Earth works in great detail.

[A slide was presented.]

Dr. FISK. Finally, this is a picture Galileo took on its way by the Earth. There is a very interesting movie, if you have not seen it, of the fly-by of Earth by Galileo. Of course we are on our way out now to an astroid with a fly-by in the fall of Gaspra with Galileo, and we can talk later, if you like, about the impact of the current issue.

Senator GORE. I have seen that film, Dr. Fisk. I think Martin Marietta participated in making that, did they not?

Dr. FISK. Not that Galileo one, I do not think. This is the one that shows——

Senator GORE. I have that mixed up with a solar system fly-through, the one that has the Earth spinning as Galileo pulls away from it. It is really a spectacular film. I wish it could be shown in every school around this country

Dr. FISK. I agree. Everyone remembers the impact of the old Apollo VIII picture of the Earth. This is, I guess, our modern-day version. We have a video now of the spinning Earth.

This is obviously just kind of a smattering of the science results. The volume of papers that is coming out from Hubble and from Magellan and from Galileo and from COBE is dominating the literature now in science, and I think in all cases these are truly phenomenal successes.

[A slide was presented.]

Dr. FISK. With your permission, I am going to take a little turn here to Mission to Planet Earth and then be prepared to answer your questions.

This is by way of an update. You may recall that since we talked last year the principal event that has occurred in Mission to Planet Earth in the United States is that we have confirmed the payload to fly on the first EOS–A spacecraft. That was the result of a fairly elaborate process not only through the normal formal selection of payloads by our announcement of opportunity process, but we convened last fall what we call the payload panel.

We put together the interdisciplinary scientists on EOS, the people that are actually going to use the data, and we said tell us what it is we should do. Tell us what the payload should be. Give us any advice on how to do this mission differently from what we have been doing. Their recommendation fed into the selection of that payload.

This chart—and I think you have hard copies in front of you—I was afraid that this could not be read. This is a calendar chart of all the missions that are going to fly prior to the launch of EOS–A, and the only criteria that is on this chart is that the data is available to the U.S. research community to study global change problems.

So, this includes international missions for which we have a data exchange policy and includes operational missions where the data is available through the World Meteorological Organization. There are, in fact, an enormous number of missions that are going to fly. In fact, if you count dollars on this, there is about 8 billion dollars' worth of satellites that are going to be launched prior to EOS–A that are going to tell us about global change activity.

Now we looked at EOS–A and said: "What should it be?" Is it as it should be, in fact the next logical step beyond those missions? It should be an improvement in what is going to occur over the next 8 years in terms of resolution, in terms of sensitivity. Science evolves by people making more detailed, better, comprehensive measurements. We know the limitations that will exist on these measurements that will be made over the next 8 years.

We need to have EOS take the next step beyond that. It is not, however, a step that is some step function, some enormous jump.

[A slide was presented.]

Dr. FISK. This chart illustrates that in the case of all those missions what are going to fly are instruments which are the precursors of EOS instruments. They are either instruments which are making the same measurements with less resolution or sensitivity or, in some cases, they are actually the same instruments. So, on these satellites that will fly in advance of EOS are instruments which continue the data stream for some long period of time here, and then EOS makes the next step in resolution and sensitivity.

So, you can see in the case of MODIS–N, which is a workhorse instrument on EOS, the AVHHR's, which fly on the NOAA satellites, are in the same spectral band. In the case of the AVHRR, you are talking about an instrument which has some five to seven channels. In the case of MODIS–N, you are talking about an instrument that is 35 channels.

In all cases, the EOS–A instruments are chosen to be the next step beyond the instruments that are going to fly over the next 8 years. Now you pay a price when you take that step, and the price that you pay has two dimensions. One is, of course, you get more complex instruments. If you want to have a 7-channel instrument on AVHRR and a 35-channel on EOS, it is a bigger, more complicated instrument. However, the principal price that you pay is that if you are going to take this next step in resolution and sensitivity, you have to be prepared to make the atmospheric corrections at the same time.

It does you no good to fly a 35-channel MODIS–N, which will give you a quantitative understanding of the Earth better than you could do with a 7- or 8-channel alone; the only way you will get that quantitative understanding is if you have the atmospheric information at the same time to make the correction. That is the so-called simultaneity argument.

But if you are going to make the next step in resolution and sensitivity, you have to be prepared to make the atmospheric correction measurements at the same time you make the measurement; otherwise, it was not worth your effort to make that increased resolution and sensitivity.

[A slide was presented.]

Dr. FISK. So, the payload that has been chosen for EOS–A, which is summarized here, is a combination of atmospheric measurements, ocean measurements, and land measurements that need to be made on the same spacecraft so the information we derive from the atmosphere here allows you to make the corrections to the land surface imaging instruments.

Again, if you are going to make this increase in resolution and sensitivity, you need this data; otherwise, it was not worth doing so. That is an argument which has been confirmed by our payload panel. It is an argument that has been confirmed by the Academy, and hence the selection for the EOS–A platform.

End of statement.

[The prepared statement of Dr. Fisk follows:]

PREPARED STATEMENT OF DR. LENNARD A. FISK

I am pleased to have the opportunity to appear before the Subcommittee today to report on the status of NASA's space science and applications program and our plans for the future.

My focus today will be on three main themes: 1) NASA has a robust space science program, which is balanced among the core space science disciplines and which emphasizes the study of our own planet with the Mission to Planet Earth; 2) we have a Strategic Plan in place that will provide a roadmap for maintaining this robustness into the next century; and, 3) we have, as an agency, an appropriate balance between science and supporting infrastructure which will perpetuate the position of the United States as a world leader in space science research.

THEME 1

This is my fourth year of presenting the space science and applications program to this Subcommittee. Over the past 3 years we have seen the evolution of a program full of promise and potential to a program of accomplishments. We are in the midst of one of the most exciting and interesting periods in the history of space exploration—a period referred to as the "Second Golden Age of Space Science." This "golden age" holds the potential for expanding our knowledge and understanding of scientific phenomena ranging from the intricacies of the universe to the subtleties of our very own planet. Over the next few years we will see an ever increasing level of activity in space science. Many of our planned missions are moving forward in their development and construction, culminating in their launch and operation. The resulting return in scientific data will be astounding in its depth and breadth.

Although the "golden age" to date has been primarily focused in the areas of astrophysics and planetary exploration, this year will see us embark on the exploration of our own planet with Mission to Planet Earth. Mission to Planet Earth is unlike any other NASA space science program. It is not intended to increase incrementally our knowledge of Earth. Rather, it is intended to increase with all due haste our knowledge of all aspects of the Earth system to a sufficient level of understanding to assist in making sound policy decisions.

During the next several years, our knowledge of Earth should increase substantially, as NASA will participate in 19 Earth science missions to study various aspects of how the Earth works. This year will see the launch of the Upper Atmosphere Research Satellite (UARS) which will make definitive measurements of the chemistry and dynamics of the upper atmosphere, and thus of ozone depletion. It will be followed next year by TOPEX/POSEIDON which will reveal more about the circulation of the world's oceans than all the ships in history. The NASA Scatterometer will study wind stress on the oceans. The ATLAS Spacelab missions will study the atmosphere, and the Shuttle Radar Laboratory will observe the topology of the land. Our international partners, the Japanese, the Europeans and the Canadians, will also launch 7 missions, some of which will carry U.S. payloads, and many of which we will help track in return for access to their data. And the National Oceanic and Atmospheric Administration will continue to operate meteorological satellites.

The FY 1992 space science and applications budget focuses on three themes: the timely execution of core space science missions, the vigorous pursuit of Mission to Planet Earth, and increased support for basic research. These themes are consistent with the recommendations of various outside advisory bodies and the guidance of the Congress. There is, however, one major difference in this budget compared to

those I have presented to you in previous years. The FY 1992 budget request does not include a major new start for space science. Rather this budget, with its growth over the FYI 991 budget, simply allows us to continue on schedule the missions and programs committed to in previous years by the Administration and the Congress. The proposed budget does include funding for a new small mission to develop a recoverable life sciences satellite called Lifesat. This satellite will help to define radiation protection requirements for the long-term habitation and exploration of space and thus constitutes a key contribution to Mission from Planet Earth. Another critical element of the FY 1992 budget is an augmentation to the research and analysis program—which is the critical linchpin to a world class science research community in universities and NASA centers.

I believe that the budget presented to you is a balanced space science and applications budget; we are approximately 20 percent of the NASA budget and the resources are applied in accordance with the themes of the Space Science and Applications Strategic Plan. We need your support for this budget in order to assure the health and well being of the current operational program, as well as programs in development.

Permit me now to describe in more detail some of our recent accomplishments and our plans for 1991.

1990: A Year of Successes and Challenges

The year 1990 was one of extraordinary activity for space science, perhaps the most active year in several decades. Launches included Pegsat, the Hubble Space Telescope, the Roentgen Satellite, the Combined Release and Radiation Effects Satellite, Ulysses, and the flight of the Astro Spacelab mission. Missions launched in 1989 also successfully met major milestones in 1990, including Galileo's Venus and Earth flybys, the Cosmic Background Explorer all-sky survey, and the initiation of the Magellan mapping phase.

The Hubble Space Telescope (HST), of course, presented challenges with the discovery that its primary mirror exhibits spherical aberration. This problem notwithstanding, HST is proving itself to be an exemplary observatory, capable of seeing objects in visible light much more clearly than ground based telescopes and making extraordinary observations in the ultraviolet wavelengths, which are obscured from the surface by the Earth's atmosphere. HST is the world's premiere astrophysical observatory today, and we remain confident that over the next few years we will successfully restore as much of HST's original capabilities as is technically and scientifically prudent.

More immediately, NASA scientists analyzed global temperatures from the 1980's to offer insights into potential global warming. Though no net trend could be seen within the last decade, observations indicated that the 1980's were warmer than the 1970's. In addition, reanalysis by NASA scientists of data from the Total Ozone Mapping Spectrometer (TOMS) indicated that yearly ozone depletion over the Northern mid-latitudes is more severe, and of longer duration than previously believed. NASA also expanded its commitment to study the Earth, receiving approval from Congress to begin the Earth Observing System (EOS), a series of satellites that will use the perspective from space to observe the Earth as a global environmental system, and to provide the space-based measurements required by the U.S. Global Change Research Program.

We continue to proceed in our commitment to understand the changes occurring in our own planet Earth. In January, we selected a payload of 11 instrument investigations for the first spacecraft in the EOS-A series to provide a concentrated and coordinated study of the causes and effects of global warming. The final determination of the instrument manifest on subsequent spacecraft will be made after development is underway on the initial set. This approach is intended to allow for the continuing evolution in mission planning that is expected to result from the development of new technology, improved understanding of measurement requirements, and the availability of alternative sources of data.

The second spacecraft series, EOS-B, currently planned for flight 2½ years later, is devoted to measurements of tropospheric and stratospheric chemistry, ocean circulation, glaciology, and plate tectonics. In contrast to the initial EOS-A spacecraft, which carries a full suite of instruments on a single spacecraft, the EOS-B series may be conducted using multiple smaller spacecraft with smaller numbers of instruments per spacecraft. We expect to issue a Request for Information (RFI) to industry later this Spring seeking input and suggestions on how best to provide the needed EOS-B observations.

It is important that as we execute the EOS program we continually review it to ensure that we are proceeding in a cost-effective and timely manner that will yield the scientific results required by the U.S. Global Change Research Program. Over

the next several months, the EOS Engineering Review Advisory Committee will for EOS-A assess whether any alternatives are significantly superior to the current program and for EOS-B, to assist NASA in adopting a new design which best meets the stated objectives. The Committee is expected to issue its final report in September 1991.

In addition, our international partners, the European Space Agency (ESA) and Japan, are planning to build spacecraft that include accommodations for U.S. scientific instruments. Supplementing these components will be a series of smaller Earth Probe satellites with specialized instrumentation and orbits for investigations that cannot be accomplished otherwise.

To make optimum use of the data from these upcoming missions, we intend to improve computational capabilities in Earth science, and to enhance the access of researchers to these data through networks and archiving facilities. The EOS program includes an EOS Data and Information System (EOSDIS), essential elements of which will be brought online in 1994, in advance of the launch of the EOS spacecraft. EOSDIS will be used to derive maximum information from existing and upcoming missions. In turn, the data from these missions will be used to test and perfect EOSDIS in advance of the larger data flows from the EOS spacecraft.

Data alone does not yield understanding. Understanding requires scientists interpreting the data, developing concepts for the processes that control Earth, and building predictive models of its future. The EOS program will include funding to effectively double the research community that will dedicate itself to understanding global change.

Significant progress in the Life Sciences was made in 1990. The Extended Duration Medical Program made substantial progress toward documenting the physiological changes that potentially affect Space Shuttle crews' capability for landing and egress. Investigations were flown on all five Shuttle missions during 1990. The program is on schedule to support a 13-day flight of the United States Microgravity Laboratory (USML-1). In addition, the NASA Specialized Centers of Research and Training (NSCORT) program was initiated with three Centers being selected: Kansas State University, Purdue University and the University of Rochester.

In 1990, we conducted approximately 30 suborbital rocket flights and 25 balloon flights in support of space science. Space science missions conducted during 1990 included major, moderate and small missions, reaffirming NASA's continuing commitment to a balanced space science program.

1991: Another Promising Year for Space Science

This year will build on the successes and lessons learned in 1990; providing us with additional early returns from missions launched during the last 2 years, and a sequence of exciting new launches. These new launches, along with the continued development of planned missions, constitute important investments in our country's future.

NASA's current launch manifest calls for four major space science launches during 1991; three on the Shuttle and one aboard an expendable launch vehicle. The Gamma Ray Observatory was successfully launched on the Space Shuttle Atlantis on April 5, 1991. The three other missions planned for 1991 are the Upper Atmosphere Research Satellite, the Extreme Ultraviolet Explorer, and the first Spacelab Life Sciences mission, all of which reflect significant strides in these various science disciplines. In addition to launches, Magellan will complete its primary mapping mission and begin its extended mission in May, and Galileo will obtain data on its flyby of the asteroid Gaspra, both of which are significant scientific milestones.

The Soviet Union is scheduled to launch NASA's Total Ozone Mapping Spectrometer (TOMS) on one of its "Meteor" remote sensing satellites during August. This instrument will complement the long-term data set being gathered by a TOMS instrument on Nimbus-7, which has operated since 1978. It will also allow time series evaluations of environmental trends to continue through the end of the century, providing increased insight into global and regional changes in ozone concentrations. This cooperative mission with the Soviet Union will be followed later by the launch of identical TOMS instruments on a U.S. spacecraft in 1993, and on a Japanese spacecraft in 1995. All three missions will serve as precursors to NOAA instrumentation planned for use in the Earth Observing System (EOS) program.

The Advanced X-ray Astrophysics Facility (AXAF), the X-ray element of NASA's Great Observatories program, will pass a major programmatic milestone later this year with the completion of the fabrication and initial testing of its first pair of X-ray mirrors. AXAF, the third Great Observatory, is scheduled to be launched in the late 1990's and will operate for approximately 15 years. AXAF will focus on the "violent" universe, investigating the existence of stellar black holes and dark matter,

and the processes surrounding galaxy clusters and superclusters, supernovae, neutron stars and stellar evolution.

Our Nation's first global change satellite, the Upper Atmosphere Research Satellite (UARS), will be ready for launch in September. UARS will provide a global database necessary for understanding the chemistry, dynamics and energetics of the upper atmosphere and the effects of solar radiation on these characteristics. UARS will also explore the susceptibility of the upper atmosphere to long-term changes in the concentration and distribution of key atmospheric components, particularly ozone. UARS will be a vital component of NASA's long term program in upper atmospheric research.

Mr. Chairman, 1991 is shaping up to be another impressive year for NASA's space science and applications program. However, as we move forward into the future, we cannot lose sight of our strategic direction. As more and more planned launches become reality, the natural tendency is to become concerned only with the immediate future, to concentrate only on the next milestone or the next mission. We remain committed to ensuring that our Nation's space science program does not become a victim of short-sightedness.

THEME 2

Since 1988, the Office of Space Science and Applications (055A) has had in place a comprehensive strategy for managing our programs. The elements of the 055A Strategic Plan have remained constant throughout, namely: 1) Establish a set of programmatic themes; 2) Establish a set of decision rules; 3) Establish a set of priorities for missions and programs within each theme; 4) Demonstrate that the strategy can yield a viable program; and, 5) Check the strategy for technology readiness and for consistency with resource constraints, such as budget, workforce, facilities, and launch vehicle availability.

To date, the 055A Strategic Plan has served NASA and the Nation well, providing us with a clear vision of the future of space science and a detailed strategy for making that future a reality. The Strategic Plan has guided our actions over the last 3 years and has been adapted, as necessary, to meet the changes and challenges that have arisen. The 1991 Strategic Plan reflects a transitional year in which we focus on carrying out the ongoing space science program and strengthening our research base to reap the benefits of current and future missions. The Plan is built on interrelated, complementary strategies for the core space science program, for Mission to Planet Earth and for Mission from Planet Earth. Each strategy has it own unique themes and mission priorities, but they share a common set of principles and a common goal—leadership through the achievement of excellence.

The OSSA Strategic Plan has aged well because it is built on a solid foundation of consensus among the major groups interested in space science, and because it has been updated annually to ensure that it remains consistent with the realities of the 1990's. The OSSA Strategic Plan reflects a comprehensive and balanced space science program, proposed by NASA with guidance from the science community; a plan that the Congress and the Administration have endorsed. It reflects the reality of the current constrained fiscal environment, proposing no major New Starts during Fiscal Year 1992. It contains increased emphasis on, and additional funding for, Research and Analysis (R&A) activities; reflecting NASA's continuing responsiveness to the requirements of the scientific community. And it remains consistent with the recommendations of the Advisory Committee On the Future of the U.S. Space Program (Augustine Committee).

NASA remains firmly committed to fulfilling the OSSA Strategic Plan in its entirety, as called out in the Augustine Committee's report: "Recommendation 2: That, with respect to program content, the existing strategic plan for science and applications proposed by NASA with input from the science community be funded and executed."

The next edition of the OSSA Strategic Plan should be available shortly. Consistent with our intent to keep the plan timely, OSSA will be spearheading a comprehensive review of the Strategic Plan this coming Summer with significant input from the scientific community. Our goal is: to extend the duration of the Strategic Plan through the end of this century and into the early years of the next; to establish our priorities for space science missions through Fiscal Year 1998; and to assess the likely priorities for the period Fiscal Year 1999-2003. This months-long effort will culminate in a week-long workshop in August with our advisory committees.

THEME 3

Finally, Mr. Chairman, I would like to address NASA's commitment to assure U.S. leadership in the field of space science and applications. This is not attained

merely through budgetary support for the space science and applications program. Rather it is the entire NASA institution—the people, the facilities, the resources together with the university community and industry that are responsible for a world class science program. The space science and applications program depends on all elements of the NASA program to be world class—the Shuttle, the Space Station, the Deep Space Network, the Expendable Launch Vehicles, the Tracking and Data Relay Satellite System, the Space Research and Technology Program you cannot have one without the other elements. It is the commitment to investments for the future workforce, to assure a world class science program—both for this program as well as the other elements of the agency. It is the initiation of Global Change Research Fellowships that will nurture the future researchers to push towards an understanding of the feedback systems of our fragile environment. The budget that you have before you for NASA is a balanced one, which provides the needed support for space science and applications across the entire agency, and which without such support the space science and applications program cannot succeed.

SUMMARY

As we begin 1991 and look forward to 1992, our Nation's space science program is doing well and its future appears bright. A number of NASA's major missions have already, or will within the next year, enter into their primary operation phase. During 1991 and 1992, we can expect that missions such as HST, COBE, Magellan, and Galileo, will continue to produce new discoveries and contribute to the ever growing body of scientific knowledge.

Progress is anticipated during 1991-1992 for a number of major programs currently under development. The Earth Observing System (EOS), Advanced X-ray Astrophysics Facility (AXAF) and CRAF/Cassini missions will be completing a number of major programmatic milestones. On these and other missions, NASA is building the ground work in 1991 for new discoveries in 1992 and beyond; some missions will not reach their primary operational phase until late in the 1990's, or early in the next century. A more detailed status for OS5A's major missions is contained in the enclosure entitled "Status of Major Missions."

Additional missions scheduled for launch during 1991-1992 will build on lessons learned from previous space science missions, as well as initiating some important firsts. During this period, NASA will launch the first in a series of missions dedicated to understanding global change, the Upper Atmosphere Research Satellite (UARS). NASA will also make considerable progress on the newly approved Earth Probes program, opening the door to even more advances in our understanding of global atmospheric and environmental trends. We recognize the urgency to pursue these missions with deliberation and speed; we are proceeding under this premise.

It is clear that a new era in space science has begun. The decade of the 1990's will be a very important time to concentrate our efforts on reaping the benefits of the data obtained from missions recently launched, and to continue the development of future missions approved over the last few years. Some of these missions are just beginning to bear fruit, while others are just getting off the ground. Many of the newly approved missions are entering crucial phases of their development and will need to be nurtured carefully. It is our mutual responsibility to assure that we stay on course and look to the future. We have a responsibility to future generations to nurture the various elements of this program to better understand our Earth and the universe in which we reside. NASA remains committed, with the help of this Committee and the Congress, to ensure that our vision of the future becomes a reality.

STATUS OF MAJOR MISSIONS

- *Operational Missions*

Hubble Space Telescope (HST).—Launched on April 24, 1990, HST's flight and ground systems are all operating within specification, with the exception of the effects of spherical aberration in the primary mirror and disturbances ("jitter") resulting from thermally-induced problems with the solar arrays. The spherical aberration problem is now well understood; the Optical System Board of Investigation (Allen Board) issued its final report on the cause of this problem on November 27,1990. Earlier this month, NASA's test of the new version of jitter-reducing software (SAGA-GA) was successful. HST has now been successfully controlled by gyros, coarse track and fine lock using this software, resulting in a significant reduction in the solar array-induced jitter (approximately 60 percent while in fine lock) and an associated improvement in operational efficiency. This version of the software will now be implemented on a permanent basis. Work continues, in consultation

with the European Space Agency (ESA), on measures to fully alleviate the effects of the solar array-induced disturbances.

All of HST's science instruments are fully operable. Orbital Verification was completed during November 1990; Science Verification continues to progress well with completion scheduled for November 1991. Guest Observer (GO)/Guaranteed Time Observer (GTO) programs are being integrated into the remainder of Science Verification. Outstanding science results continue to accrue from the first of NASA's Great Observatories with several images being released since May 1990, including recent Saturn observations that continue to demonstrate HST's ability to conduct world-class science. In fact, a special session of the 1991 American Astronomical Society (AAS) winter meeting was devoted to results from HST. Progress continues on plans for the 1993 Servicing Mission. The basic payload consists of the replacement Wide Field/Planetary Camera (WF/PC II) and the second solar array set. A replacement gyro package and additional optical system corrections are under study.

Gamma Ray observatory (GRO).—The Gamma Ray Observatory (GRO) was successfully launched aboard the Space Shuttle Atlantis on April 5, 1991 into a 244 by 241 nautical mile orbit. On Flight Day 3 (April 7), GRO was successfully deployed from the Orbiter after a spacewalk (Extravehicular Activity—EVA) was performed to deploy GRO's high-gain antenna.

To date, no significant problems have been encountered with operations of the Observatory; all thermal conditions, power system operations and communications have been nominal. On April 15, 1991, low voltage power was successfully applied to all four instruments. After the initial instrument checkout is completed, GRO's 15-day on-orbit instrument calibration activities will commence. The Observatory is expected to be fully operational during May 1991, at which time GRO will commence its 15-month all-sky survey.

Cosmic Background Explorer (COBE).—Launched on November 18, 1989, the Cosmic Background Explorer (COBE) spacecraft continues to operate nominally. COBE completed its all-sky survey during June 1990, and depleted its on-board helium supply, as expected, in September 1990. All six Differential Microwave Radiometer (DMR) channels, and four of the six bands of the Diffuse Infrared Background Experiment (DIRBE), continue to collect science data.

COBE's significant scientific accomplishments continue to astound and impress the scientific world. During 1990, COBE produced the most precise measurement of the Big Bang infrared spectrum, the first near infrared image of our Milky Way Galaxy, and the most precise anisotropy maps assembled to date. COBE's near infrared image of our Milky Way Galaxy was selected by Popular Science Magazine as one of the "100 Best of What's New for 1990."

Galileo.—Since launch on October 18, 1989, Galileo has traveled over 890 million miles and is approximately 40 million miles from Earth. Its principal mission is to study the planet Jupiter, its atmosphere, magnetosphere, and four Jovian satellites. Galileo's performance to date has been excellent. Galileo's Venus gravity assist flyby was successfully completed in February 1990. Data from this Venus flyby was downlinked in November 1990, providing the best visible light imaging obtained to date, and the first ever infrared imaging and spectroscopy below Venus' cloud deck. In December 1990, Galileo flew by Earth, providing impressive scientific data (and over 3000 images) of the Earth/Moon system.

On March 26,1991, the spacecraft entered a safe mode due to a transient anomaly. Galileo will return to normal operations on April 29,1991. On April 11, Galileo's High Gain Antenna was deployed. Deployment of the antenna was not fully successful, and analysis of the cause and possible corrective actions are currently under review. This incident does not affect the spacecraft's ability to navigate to Jupiter. While Galileo is on its journey to Jupiter, the spacecraft will continue its collection of interplanetary data. Scientists and engineers are planning for the spacecraft's asteroid encounters and Jupiter tour.

Magellan.—Launched on May 4, 1989, Magellan was inserted into orbit around Venus on August 10, 1990. Radar mapping activities are proceeding smoothly, with over 1,626 orbits successfully mapped since initiation of mapping on September 15, 1990. To date, over 75 percent of the planet's surface has been mapped. One of our scientific mission objectives—to map at least 70 percent of the planet—has been achieved ahead of schedule, and by the end of the first cycle on May 15, 1991, we expect to have mapped more than 80 percent of the surface. Scientific results released to date have been impressive; special sessions at the December meeting of the American Geophysical Union (AGU) and the March meeting of the Lunar and Planetary have been devoted to Magellan.

The spacecraft continues to operate well with only minor anomalies. The loss of signal events that have occurred since Venus Orbit Insertion (VOI), resulting in telecommunication interruptions, are still not well understood and could reoccur.

On-board changes have been made to shorten the interruptions so that only four orbits' of mapping are lost. Problems with the operation of the on-board data recorders are in work. Troubleshooting on Tape Recorder A to characterize the problem and identify possible solutions continues. Tape Recorder B performance has been solid and shows no degradation.

Ulysses.—Ulysses is a cooperative mission with the European Space Agency (ESA) to study the Sun at high polar latitudes. Since it was launched aboard the Space Shuttle Discovery on October 6, 1990, the Ulysses spacecraft has traveled approximately 333 million miles and is performing well. By mid-December 1990, the spacecraft "wobble" was under control, and an appropriate strategy is in place to handle recurrences. Expectations that the undesired motion might recur in February and March proved to be unfounded.

The spacecraft's power and propulsion systems are performing well and the thermal condition of the spacecraft is good. Routine operations commenced in January 1991—operational control was transferred from the European Space Research and Technology Center (ESRTEC) to the European Space Operations Center (ESOC) in early January. Subsequent to post launch checkout activities and instrument calibrations, all science instruments are operating and returning data. A period of intense solar activity was experienced in late March which temporarily affected data from three instruments. All instruments were quickly restored to full function after solar activity subsided. Trajectory corrections have been successfully completed in preparation for the Jupiter gravity assist scheduled for February 1992, this maneuver will propel Ulysses out of the ecliptic plane and into position to observe the Sun's polar regions. On April 14, 1991, Ulysses reached the half-way point on its journey from Earth to Jupiter.

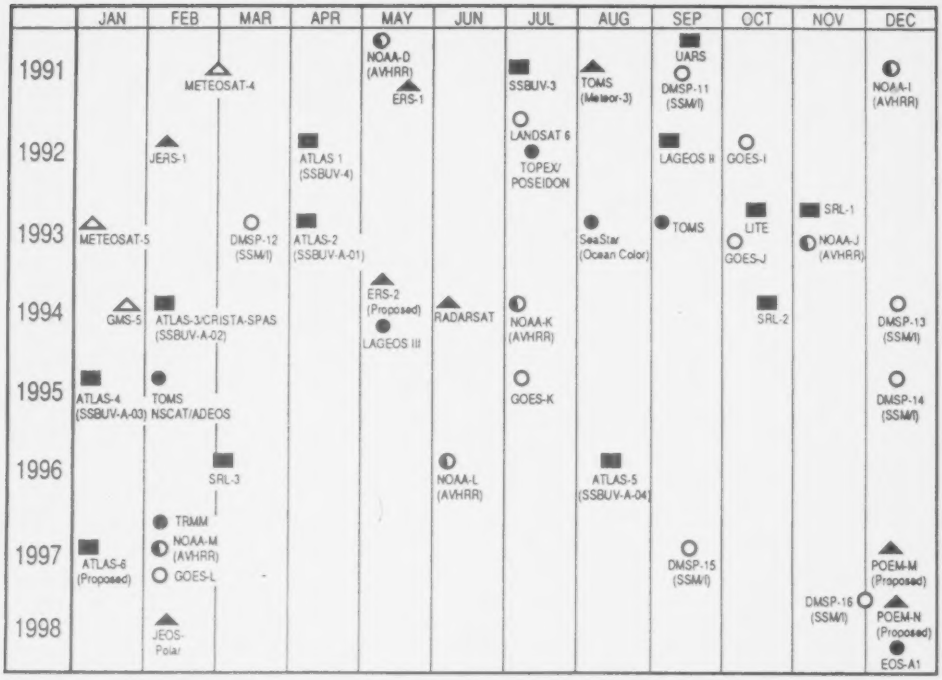
Combined Release and Radiation Effects Satellite (CRRES).—On July 25,1990, the Combined Release and Radiation Effects Satellite (CRRES), a cooperative program with the U.S. Air Force, was successfully launched into orbit. CRRES, with its 24 chemical canisters, is designed to study the Earth's magnetic and electrical fields and radiation belts. The release of lithium and barium ions from these canisters is used to trace the field lines of the Earth's magnetosphere. A primary science objective of CRRES is the simulation of artificial particle precipitation. The South Pacific chemical release campaign in September 1990, first Northern Canada high altitude campaign in January 1991, and the second Northern Canada high altitude campaign in February 1991, have been successfully completed with two, six, and two releases, respectively. The purplish barium and red lithium clouds were observed and tracked by ground stations, scientific aircraft and satellites. A sounding-rocket campaign in the South Pacific made sub-orbital studies in conjunction with the CRRES satellite. Releases from a similar mission, Pegsat, were seen in the Spring over parts of Northern Canada. Additional Caribbean releases are planned for July/August 1991.

UPCOMING LAUNCHES

Spacelab Life Sciences Mission (SLS-1).—A Spacelab module outfitted for the first Spacelab Life Sciences Mission, SLS-1, was transferred to the Orbiter Processing Facility (OPF) and installed into the Space Shuttle Orbiter (Columbia) during March 1991. Three of SLS-1's four planned Joint Integrated Simulations (JIS #1-4) have been completed; JIS #4 is scheduled for completion in early May 1991. The Headquarters Mission Readiness Review is scheduled for April 30 and SLS-1 remains on schedule for a May 1991 launch readiness.

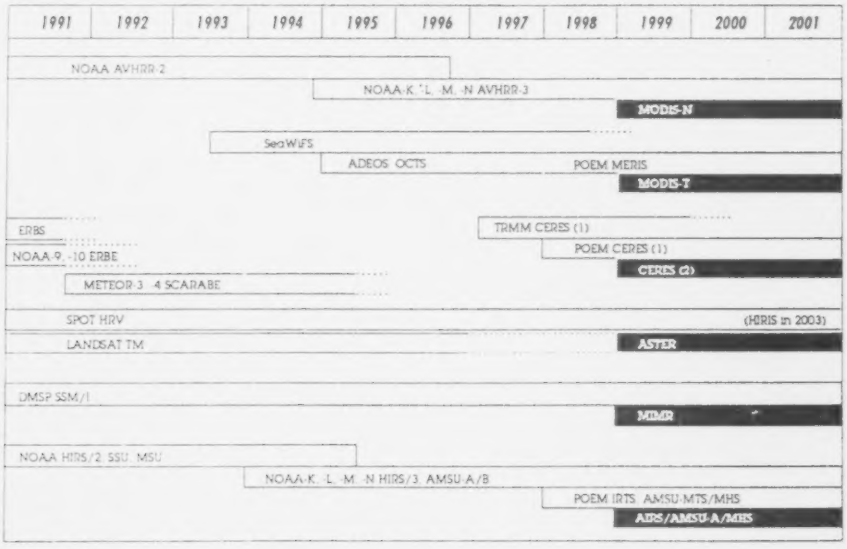
Upper Atmosphere Research Satellite (UARS).—The Upper Atmosphere Research Satellite (UARS) Central Data Handling Facility (CDHF)is now up to its full capability of 140 million instructions per second. The UARS mission crew was assigned in December 1990. All ten UARS instruments have been redelivered to General Electric, with observatory integration and testing expected to be completed in April 1991. The Observatory is scheduled for shipment to the Kennedy Space Center (KSC) during May 1991, and will later be integrated into Space Shuttle Discovery in support of a September 1991 launch readiness.

MISSION TO PLANET EARTH ERA*



* Dates for US Missions are Estimates and Reflect Current (March 1991) NASA Manifest and Planning, as Well as Planning by NOAA and DOD. Dates for Foreign Missions are Estimates Provided by Those Nations.

► EOS-A Measurement Continuity and Evolution



► EOS-A! Essential Synergistic Payload

Senator GORE. Very good. Thank you.

Let us deal with some of the space science questions other than Mission to Planet Earth first and then we will zero in on Mission to Planet Earth.

Dr. Fisk, first of all let me ask you about the Hubble space telescope. You have shown a series of pictures providing evidence that despite the spherical aberration good science is being performed, and that is indeed welcome news. However, I would like to focus on the planned mission to repair the Hubble.

It has been reported that you have said the development of the corrective optics space telescope axial replacement or COSTAR is now in doubt because it may not work and it would drain $35 million from future upgrades slated for the Hubble later this decade. Is NASA taking the position that it may not even undertake a mission to attempt to fix the Hubble's flawed optics? Is that what you are saying, and is the current repair mission still scheduled for 1993?

Dr. FISK. It is. I am not sure where that quote from me comes from, but let me tell you what the story is. We are scheduled to go in 1993 to do a repair mission. We will beyond any doubt replace the Wide Field Planetary Camera with its replacement camera, which contains, in the camera, optics that fix the spherical aberration. We are going to replace the solar array, which has given us the jitter problems. Though we have made substantial progress, the best thing to do is simply replace the solar array.

And we have a final decision to make, here in about another 2 weeks on COSTAR. Basically, the plan we are on, we convened a science panel and we said "Is COSTAR the right thing to do?" Is it the right thing to do even if it causes us to delay some of the instruments beyond the Wide Field Planetary Camera replacement,

the so-called STIS and the NCMOS, the second and third generation instruments because money is tight?

If we had to do COSTAR at the expense of those instruments, would the science community say that was the right thing to do? And they said it was. We accepted that guidance and now the only remaining issue is, Is there any technical issue on COSTAR that would make it difficult or impossible to do? We have not seen one, but we have a final review on May 1 and 2 called the preliminary design review. If the outcome of that is that there are no showstoppers, we are going to go ahead and do it.

Senator GORE. Very good. When you talk about that finding, that indeed it was the right thing to go ahead and put COSTAR up there, is that the science test group that met in early March you are referring to?

Dr. FISK. There was a science task group that met in early March. There have been a whole series of panels that have met, some evaluating the optics, some evaluating the relative science priorities. And in the sort of late February–March timeframe was a group that evaluated the science priority.

Senator GORE. When is this last review scheduled?

Dr. FISK. I believe the preliminary design review is in very early May and then the decision will come to me for final resolution.

Senator GORE. It is my understanding that the COSTAR mission would stretch the shuttle's capabilities, requiring three or four 6-hour, two-person EVA's. Can you comment on that and on the EVA demands of the 1993 repair mission?

Dr. FISK. As I recall, it is three, but that does not stretch. It is a challenge, but it does not stretch the shuttle capability. We have been working closely with the astronaut corps and Johnson Space Center on this, and within those three EVA's, our current timeline, there is a fair amount of reserve, and we will not be up against the stops at three EVA's.

Senator GORE. Now, in addition to COSTAR, which sounds like you believe it is on track, there are other alternatives. A second possible solution that has been discussed is the afocal variation system proposed by an outfit called Infinity Optics. Given what you know about the complexity and difficulty in ensuring the success of COSTAR, what considerations has NASA given to the AVS?

Dr. FISK. Well, let me tell you what I know about this. There was a whole series of ideas that were presented as possibilities, and we put together an independent optics panel review team which was chaired by the director of the Institute of Optics at the University of Rochester, which is of course one of the better known optics places. The team included a variety of optics experts from around the country, and, in that case, they rejected that idea as not workable.

Senator GORE. OK. Are you including the space telescope users in the evaluation of the possible fixes?

Dr. FISK. Absolutely, and particularly in this panel that we just discussed that met in February–March. It was heavily dominated by the people who will use the data.

Senator GORE. Let me turn to the issue of data management. In the coming weeks, as you know, we intend to hold a hearing looking closely at the issue of data management. That is an issue of

special interest to me and to Senator Pressler as well. And yet because it is so important to space science I would like to ask just a few questions about it here today, even though we are going to home in on it in a special hearing a little later.

Last September the General Accounting Office issued yet another report critical of NASA's data management practices. In particular GAO recommended that NASA, one, act to ensure that missing data from past missions is archived; two, revise its data management policy to ensure that all valuable data is properly archived from now on; and, three, work to increase participation of scientists in data management and archiving.

Since that report was issued 7 months ago, what steps have been taken to implement these recommendations?

Dr. FISK. A number of things have happened. First of all, according to our current statistics, about 90 percent of all data that is of a usable product is in fact archived at the moment. That is our findings on the data that is archived.

And obviously what you would like is 100 percent and there is in fact a rapid increase in the amount of data that is being archived and being made available. We also have, of course, the data initiative in the 1992 budget, which is designed at archiving. It is funded and starts at some $3, $4 million. We are particularly concerned, of course, about the media on which we are storing data these days. There are improvements beyond magnetic tapes and we are trying to convert data storage.

I think you would find if you went discipline by discipline within NASA that the holdings are increasing and, perhaps more important, the access to the data is improving in terms of generation of directories and methods of getting access to the data.

Senator GORE. Now, since we are looking at this hearing in the context of the fiscal year 1992 authorization bill, let me ask you whether you believe NASA has sufficient resources allocated to adequately implement its data management proposals in addition to the continued development of EOSDIS, which we will discuss a little bit later in this hearing.

What specific actions are planned for fiscal year 1992 to improve NASA's data management practices, and are you confident that there is an appropriate sum in this budget that comes to the Congress?

Dr. FISK. Setting aside EOS, as you say, since I am quite comfortable about the money that is in EOS being a very large and aggressive sum, in the case of each of the data activities, each of the divisions involved has put a considerable priority on data activities.

We find, for example, the astrophysics data system is one that is being widely acclaimed now as a very good data system, and similarly in space physics and in planetary research.

I expect there is no sum too large that you could spend on data. Do we have enough? I think we have a reasonable amount, let me put it that way. We did not get turned down in any of our requests for data augmentations.

Senator GORE. Now just a few more questions in this round. One of NASA's new initiatives proposed for fiscal year 1992 is the development of LIFESAT. I notice this is also part of NASA's effort to carry out the President's human exploration initiative. Could you

please provide us with some idea of NASA's program plans for LIFESAT? How many satellites, for example, do you propose to build under this program?

Dr. FISK. I will give you a specific answer to that in a moment. The point of the program, as you correctly note, is in support of the space exploration initiative. One of the principal threats to long-distance space flight is radiation, and our knowledge of radiation damage to biological systems, humans in particular, is very limited, particularly the kind of radiation in space—heavy Z particles at high energies.

We need to understand that. It will be a major design driver in any spacecraft that someone wants to send to another planet. If you had to carry enough shielding, you might not be able to launch it. If you understood the radiation problem, you could design the shielding specifically, et cetera.

The way you do that is to get access to such radiation over the poles, and the purpose of LIFESAT is to put a recoverable satellite in polar orbit, study the impact of radiation on biological systems, and then bring them back and analyze it. There are four satellites in the system, four launches. It is a recoverable satellite with four launches.

Senator GORE. You have $15 million in your budget request. What is the total development cost and the expected operational cost?

Dr. FISK. The total is essentially $600 million, and four launches starting in 1996.

Senator GORE. And the operational costs?

Ms. SCHMOLL. Those are included.

Dr. FISK. The launch vehicles are kept, of course, in the Office of Space Flight.

Senator GORE. So, the $600 million does not include the launch platforms?

Dr. FISK. This would be comparable to citing the cost for an ACSAT, which is in the space science budget.

Senator GORE. What would you estimate to be the increment?

Dr. FISK. $270 million.

Senator GORE. So, the total would be $870 million.

What other applications in addition to the human exploration initiative will this data from LIFESAT have?

Dr. FISK. I think again radiation studies are of general interest. This is, of course, directed at a particular kind of radiation which is not that common on the ground, namely very high energy-high Z particles.

Senator GORE. Is there anything else? It is for the Moon-Mars mission and for nothing else?

Dr. FISK. Except that a recoverable satellite for biologic systems is an alternative way to do life science. You can in principle study the effects of zero G on biological systems in these recoverable satellites. You can also do that, of course, on a shuttle and spacelab, but you can get a long-duration flight probably in advance of long-duration flights on space station.

Senator GORE. You do not call this a new start as NASA commonly refers to the initiation of new programs. Help me understand the difference. You have $870 million for something that

looks like it is new. What is the difference between a new start and whatever category you are using to describe LIFESAT?

Dr. FISK. It is almost a historical issue. In the 1991 budget, last year's budget, the runout of my budget, Office of Space Science and Applications, included the LIFESAT Program. It really had very little money. I think it was $1.8 million in the 1991 budget, and it was all included in life science, but the Office of Management and Budget included LIFESAT in the runout of our budget last year.

Now, of course, that does not appear before Congress until you see the 1992 budget, so it is, I suspect, a new start to you and it is not a new start to the Office of Management and Budget.

Senator GORE. I see. And, of course, the point there is that in a time of very tight budgets, when we are scrimping to find the money to get the data we need from Mission to Planet Earth, which the Augustine Committee has said is our highest priority, and at a time when Congress is taking money out for the Moon-Mars mission, here we have $870 million added for the Moon-Mars mission. And, of course, we are going to pretend that Lifesat is not a new start because OMB was in favor of it last year as well as this year.

Now on to Galileo and then I will save my questions about Mission to Planet Earth for the second round and recognize Senator Pressler.

As I mentioned earlier, the main communications antenna on Galileo has failed to properly deploy. What is the current status of the efforts to deploy the antenna?

Dr. FISK. The antenna on it is at the moment partially deployed but not fully deployed. We have taken no action on it since the initial attempt to deploy it. We are in a major analysis phase and modeling phase. There is no urgency on this. We do not have to have the antenna out for some years in fact, so we are not going to do something silly.

There are a variety of theories as to what could have occurred—the possibility of being jammed on some tape, being jammed on some epoxy which melted and rehardened. If we can convince ourselves of those theories, then there are some steps that can be taken in terms of adjusting the temperature on the antenna to possibly free it.

We are still optimistic that there are things to be done here. As I am sure you are aware, if we are stuck with the antenna in this position, it would be of major impact on the mission.

Senator GORE. What would be the loss of scientific data?

Dr. FISK. Basically the antenna is supposed to provide data at 134,000 bits a second and we can get it back at 10 bits a second without the antenna.

Senator GORE. That would be a major loss.

Dr. FISK. Now you can still deploy the probe. You can still do fields and particles data. You can still take pictures and play them back off the tape recorder at very low bit, but obviously the number of pictures would be dramatically reduced.

Senator GORE. It has been reported that officials at JPL are considering the possibility of sending a communications satellite to Jupiter to overcome the problems created by the loss of the antenna.

Is this an option being actively considered by NASA? Would you ever propose such a concept?

Dr. FISK. It is not being actively considered at this time. It is way too early to think about that because most of us are still optimistic that we are going to find some way to free the antenna, and that is where all the effort needs to be directed at this time.

Senator GORE. Is there a window of time? You say there is no urgency. I accept what you say about that, and I certainly encourage you to take your time and do this carefully the way you are doing it. But if you come to the conclusion that it is not likely to work without another communications satellite, is there some urgency to getting that into the works in time to exploit the mission?

Dr. FISK. I am certain you would have to be prepared to launch it on a direct trajectory and get it there in time, but this statement that someone is actively considering it appeared, you know, in a newspaper, and it was an offhanded commert by one JPL employee to a reporter. There is no detail on this whatsoever.

Is it possible? Is it feasible? Could we do it? I mean, no one has even looked at trajectories.

Senator GORE. We will communicate informally with you about that.

Just to conclude my round on that $870 million, last week we identified between $2 and $3 billion needed for space station. The Congress is being invited to overlook and pretend that money is not in the space station budget, even though it is. Now we have this $870 million which Congress could, in time past, have been expected to overlook because it is presented not as a new start—a very narrow edge of a large wedge.

But in thinking forward to implement the priority recommendations of the Augustine Committee within the context of the budget constraints that we have to work with, I really do not see how NASA can pretend that an almost $1 billion add-on that is, in fact, a new start is not a new start, and pretend further that it fits within the priorities recommended by the Augustine Committee when it certainly does not appear to.

I would ask you—well, maybe we can pursue that on my second round because I have gone past my time.

I want to recognize Senator Pressler and thank him for his patience.

Senator PRESSLER. Thank you very much, Mr. Chairman.

I wonder if you could take this interesting chart, Mission to Planet Earth ERA, if you have it there, and just give a one-sentence layman's description of each activity in 1991 and 1992, and then jump to 1997 and 1998 and do the same thing.

Dr. FISK. Well, many of us think, of course, of Mission to Planet Earth starting this year because we will have the launch of several major science missions. Our European colleagues have ERS–1 going up in May. It measures oceans. It measures land, measures ice. That is European.

Senator PRESSLER. ERS–1, that is in May?

Dr. FISK. That is right. And by agreement with them we are tracking this using our facilities in Alaska and in return for that tracking we have access to the data for research purposes.

In the case of TOMS——

Senator PRESSLER. What goes up in July?

Dr. FISK. In July this is SSBUV. It is on the shuttle. It is to calibrate ozone detectors. We fly those routinely to help keep the calibration on ozone. I should point out the NOAA–D in May continues the AVHRR measurements. These are the precursor measurements to the MODIS measurements that will be made on the EOS.

TOMS is, of course, Total Ozone Mapping Spectrometer. That is a Soviet spacecraft. It will put up finally a new instrument to replace the one on NIMBUS–7 and give us the kind of calibration on ozone which has led to these recent discoveries of decreasing ozone.

We have UARS going up in September. This is the Upper Atmosphere Research Satellite. There is tremendous activity on the ozone problem in the near term. EOS does not need to step out smartly on the ozone problem because we have the UARS measurements. You have the regular series of TOMS measurements. And of course on EOS–A you will have a continuation of some of these upper atmospheric missions.

The DSMP, there is an instrument on that which is important for water vapor studies in the atmosphere. Another NOAA satellite with the AVHRR. Our Japanese friends start in 1992 with their Earth remote-sensing satellite, JERS–1, same arrangement. We are tracking it out of Alaska, have access to the data.

ATLAS–1 is a shuttle flight of atmospheric chemistry. There is a LANDSAT–6. TOPEX/POSEIDON goes in July. That is ocean circulation. LAGEOS is for geodynamics. That is the meteorological satellites.

And you continue. Just a few highlights beyond that, SEASTAR or OCEAN CALLER, that is the biological productivity of the oceans. Another TOMS to continue the series in 1993.

There is an ERS–2 coming up in 1994. Then Canadian RADARSAT; that is a U.S.-launched Canadian satellite—share the data—which measures the ice. A series of shuttle flights—Shuttle Radar Labs during this time to measure the topology of the surface of the Earth. ATLAS again to measure atmospheres.

By the time you get to 1997, you are talking about TRMM—this is the Tropical Rainfall Monitoring Mission—and radiation budget experiments. Finally, you begin to pick up the beginnings of the polar platforms. Our European friends still hold their launches in 1997, and I am sure they are going to make that date.

Senator PRESSLER. What is that?

Dr. FISK. That is a major polar platform for EOS that the Europeans contribute. Similarly, the JEOS is the Japanese polar platform, part of the EOS Program, and then our own in 1998.

Senator PRESSLER. OK. That is a good chart. What do you think the chances are that that schedule will hold or be accelerated? Do you think it is fairly realistic?

Dr. FISK. Which?

Senator PRESSLER. The whole schedule.

Dr. FISK. I think for most of these launch dates, the ones that are labeled other than proposed on this I think are very firm. I am not sure that ERS–2 is going to go in May 1994. That is the proposed date of the Europeans, for example. But for the others I think they are very firm.

Senator PRESSLER. On the next page there is a data gap down there under LANDSAT–TM. What do you think follows LANDSAT–6? I see in 2 years there is a data gap in LANDSAT data between 1996 and 1998.

Dr. FISK. It would be nice to have a LANDSAT–7.

Senator PRESSLER. So, to bridge that gap that is what it would take.

Let me ask you this, Dr. Fisk. You have said that LANDSAT data could be used in these headstart activities. However, the expense of LANDSAT data prohibits its use. In fact, I have been told it costs between $4,000 and $5,000 for one scene of thematic mapper data. Personally I think this illustrates the fact that the commercialization of LANDSAT has not worked.

But I would like to hear your view on this. How can we resolve it?

Dr. FISK. There are some interesting events occurring, and I am not sure how they are all going to play out. The management of the EOSAT Corp. has changed recently, and we have started to engage in some interesting discussions with them which, although they are very preliminary, are promising.

So, I guess I am interested to see this play out. I mean, the situation that we have had up to date is as you correctly described. The data is too costly to be used by researchers, and that is a shame because it is very valuable data.

Now the question is, Are there things that can be done? I guess I am kind of encouraged by the discussions we have had in the last few weeks with the new EOSAT Corp. management, and we will have to see how they play out.

Senator PRESSLER. If the first EOS platform is not launched until the end of this decade, what kind of work will be done within the EOS data and information center prior to this first launch? I would assume some headstart activities would be conducted.

Dr. FISK. Absolutely. In fact, you know, this chart that we just talked about, this calendar chart, if you say what would really make all this be effective—here we are launching this 8 billion dollars' worth of satellites—the thing that makes it most effective is to build the data system that can incorporate data from these other satellites.

So, our drive on doing EOSDIS early. Version 0 and version 1, although we have been delayed slightly in the RFP. We are not delayed in version 0 on EOSDIS. That does not depend on the RFP. So, we are driving hard on incorporating existing data sets into the EOSDIS data system.

I think that the EOSDIS activities that need to occur between now and 1998 are to basically incorporate these existing data sets and make them accessible to the earth science community. And then, of course, the practice that results from that makes the handling of the EOS data itself a manageable problem.

Senator PRESSLER. What are we doing to ensure the preservation of LANDSAT data for long-term global change? I guess some of the things you have just mentioned.

Dr. FISK. I think that is right. In fact, one of the worries that we had recently was that there was a policy for a while that in the

absence of customers data was not in fact being taken, and then of course if it is not taken it is not accessible to the community.

So, the issue that I think we face is working with EOSAT Corp. to make sure that they are in fact using the assets that they have to provide global measurements.

Senator PRESSLER. Thank you, Mr. Chairman. I have some more questions for the record, and I shall submit them for the record.

[The information referred to follows:]

QUESTIONS ASKED BY SENATOR PRESSLER AND ANSWERS THERETO BY NASA

Question. What is the applicability of the 20 years of Landsat data that has been acquired to EOS?

Answer. The continuous data record provided by Landsat over the last 20 years is very important, both to NASA researchers and to the U.S. Global Change Research Observing System (EOS), it must be emphasized that Landsat measurements will *complement* those made by EOS instruments; EOS is not intended as a replacement for Landsat. EOS is primarily designed to provide high spatial resolution data that cannot be acquired from Landsat, and will not provide the high spatial resolution data on a global basis acquired by Landsat. Both types of data are important for global change research.

NASA agrees with the National Research Council (NRC) assessment of the importance of both past and future Landsat data as part of the data set for global change research. We believe that continuing this data set is an important issue associated with the operational Landsat program.

Question. What are we doing to make maximum utilization of this data?

Answer. According to the provisions of the Land Remote Sensing Act of 1984, management of the Landsat Program is the responsibility of the National Oceanic and Atmospheric Administration (NOAA). NASA is working with NOAA, the Earth Observation Satellite (EOSAT) Company, which operates the system for NOAA, and the U.S. Geological Survey (USGS), which archives historical Landsat data at its EROS Data Center in South Dakota, to facilitate the most complete access for researchers to Landsat data permitted by current law. Recent meetings between NASA and EOSAT officials explored issues related to future research availability of Landsat data. Follow-on meetings have been scheduled in the coming months to continue this dialog.

NASA is also working closely with other agencies to coordinate the use of Landsat data for global change research. NASA, USGS, and other organizations are planning a cooperative effort to study land cover changes in selected areas of the world, including examination of tropical forest cover. The study will concentrate on using the multiyear collection of Landsat Multi-Spectral Scanner (MSS) instrument data which was recently released by EOSAT.

Individual NASA researchers use Landsat data for a variety of purposes, including research on biogeochemical cycles, geology, geodynamics, ecology, and applications research. However, over the last several years, the commercial pricing of Landsat data has significantly reduced NASA's research use of Landsat imagery.

NASA believes the means to ensure the widest availability of data to Earth science researchers, and to expand the number of investigations using Landsat data, would be to make all of the data available to research users at the marginal cost of reproduction, perhaps through the EROS Data Center which has been designated as a Distributive Active Archive Center within the EOS Data and Information System (EOSDIS).

Question. What are we doing to ensure its preservation for long-term global change?

Answer. NOAA, through the EOSAT Company, and the USGA, through the EROS Data Center, are responsible for the long-term archival and preservation of Landsat data. As noted above, NASA is cooperating with USGS and NOAA to make Landsat data more accessible, and more stable for archival, through its Pathfinder activities.

Question. Since the EOS Data and Information System is a crucial element in NASA's Earth Observing System, what progress has been made toward designing and building the EOS Data and Information System?

Answer. NASA had made significant progress on the development of the EOS Data and Information System (EOSDIS) during the last year. Our current efforts are the result of years of study and interaction with scientists and system specialists. EOSDIS Core System studies began in 1984 with a phase A (research and de-

sign) concept study, which was in iterative process to derive and document high-level flight and ground system requirements. In parallel with this study, a system architecture was developed and reviewed by the science community in 1986 and subsequently refined. In 1988, two phase B (operations and concepts scenarios) study contracts were awarded to industry to provide preliminary and independent designs. These studies enabled NASA to validate and refine various levels of requirements, to develop the system architecture, to extend the architecture into preliminary designs, and to provide preliminary EOSDIS Core System specifications.

More recently, NASA developed a request for information (RFI) from these specifications which was released in October 1990 and which produced a significant number of comments and suggestions. EOSDIS project officials incorporated these comments in the request for proposal (RFP) for the EOSDIS Core System (ECS) contract, which was released during July 1991. Contract award is expected in late 1992, which should lead to an operational system (version I) by early 1997.

In parallel, the EOSDIS project and each of the Distributed Active Archive Centers (DAAC's) have been actively working on implementation of the EOSDIS prototype system, referred to as version 0. This effort has focused on the design and implementation of the version 0 prototype information management capability that will provide users with an overall "Earth science" view of the data available from the various DAAC systems. The version 0 effort will also involve enhancement of existing DAAC systems and user services, evaluation of standards for data formats, and general improvement of access to existing and pre-EOS NASA Earth science data. The version 0 development process began in 1990 to support on-line capability by 1994.

Question. If the first EOS platform isn't launched until the end of this decade, what kind of work will be done within the EOS Data and Information System prior to this first launching? I would assume some "headstart" activities could be conducted in order to get prepared for the data that will be acquired by the first EOS platform. Can you be specific on the types of data that could be used in these "headstart" activities? What are their characteristics and how closely do they parallel the types of data to be acquired by the first EOS platform?

Answer. The EOSDIS effort is based on the development and delivery of a series of increasingly more sophisticated and comprehensive data system capabilities to the science user communities. This phased hardware and software development approach will enable user testing and evaluation, integration, and improvement for each subsequent EOSDIS version. Each successive system version or increment will be more complex, will have more capability, and will reach more users. Each version will also be more thoroughly tested by users to ensure the effectiveness of the EOSDIS capability.

As noted above, the first major EOSDIS development milestone will be the version 0, a basic prototype system connecting a set of distributed science users to specific existing data systems and selected new data sets (designated as Pathfinder data sets) to test system design and integration and to support early research efforts. EOSDIS version 0 is as close to a system capability demonstration as will be possible for this multidisciplinary, distributed hardware and software data acquisition, analysis, information, and management system.

The data that will be involved in the version 0 activity include the Pathfinder data sets and other NASA Earth science data from past or upcoming flight missions. These data are from instruments which are similar to (i.e. data similar enough in spectral and/or spatial resolution to provide valuable experience for EOS researchers) or complementary to that expected from EOS instruments. In addition, researchers will use this data to generate products important to near-term global change research or to assist them in developing science data processing algorithms needed for EOS instruments.

NASA and NOAA are jointly working on four Pathfinder data set projects. Three of these efforts focus on data from NOAA operational instruments: the Advanced Very High Resolution Radiometer (AVHRR), the TIROS Operational Vertical Sounder (TOVS), and visible and infrared data from the Geostationary Operational Environment Satellites (GOES), while the remaining project is using data from the Special Sensor Microwave Imager (SSM/I) which flies as part of the Defense Meteorological Satellite Program (DMSP). Joint science teams are selecting algorithms for production of global change related products from these data. The goal is to produce consistently calibrated, long-term data sets; the effort will contribute important data for use by global change researchers while also offering an important opportunity in gaining experience in building high-quality long-term data sets. In addition, as noted earlier, NASA and USGS intend to establish a land cover Pathfinder data activity to process the Landsat Multi-Spectral Scanner (MSS) data recently released by the Earth Observation Satellite (EOSAT) Company for research and related data.

Data from other NASA and foreign flight missions will also be distributed through the early activities of the EOSDIS. These include numerous upcoming missions: major NASA flight missions, including the Upper Atmosphere Research Satellite (UARS) and the Ocean Topography Experiment (TOPEX/POSEIDON); flight of the Earth Probes, such as the Total Ozone Mapping Spectrometer (TOMS), NASA Scatterometer (NSCAT). and the Tropical Rainfall Measuring Mission (TRMM); and the flight of several foreign spacecraft, including synthetic aperture radars on satellites from Europe, Japan, and Canada. Handling these data sets through the EOSDIS version O, especially in the critical ares of cataloging and information management, will provide valuable experience in guiding the development and implementation of the full EOSDIS. The ability of a data and information system to support global change researchers, who will require access to varying combinations of data sets (including both in situ and remotely sensed data) crossing the boundaries of the traditional disciplines (i.e. meteorology, oceanography) will be entirely new with EOSDIS. The opportunity for both researchers and systems engineers to gain near-term experience with EOSDIS through version O is critical to eventual system success.

Question. I understand that the U.S. Geological Survey's EROS Data Center located in Sioux Falls, SD, will participate in the EOSDIS. What role do you envision EROS Data Center having in the EOSDIS?

Answer. EOSDIS will be a distributed system, with processing, archiving, data distribution, and information management capabilities provided at each of several Distributed Active Archive Centers (DAAC's). This reflects the distributed nature of the Earth science community and builds on existing computing experience and data base operations. These centers will have responsibility for data product generation, archival, and distribution.

The EROS Data Center (EDC), which contains significant archives and land observations data and is operated by USGS, has been selected as one of the EOSDIS DAAC's. As such, EDC will receive selected level O EOS instrument data and generate, catalog, archive, and distribute data and higher level products as an active, main-line component of EOSDIS. EDC will also serve as the permanent archive for NASA land processes data, including both pre-EOS data and data from EOS.

Question. Do the centers that are participating in the EOSDIS, like the EROS Data Center, have an opportunity to participate in any of these "headstart" activities?

Answer. The DAAC's, including the EROS Data Center, are playing a central role in implementing the EOSDIS version O system, with ongoing review and advice from the Science Advisory Panel and each DAAC user working group. This includes activities associated with Pathfinder data sets and data from near-term missions. The EOSDIS version O development effort will continue until completion of a transition of version O data services to the version I EOSDIS Core System. The NASA research and prototyping efforts conducted at the EOSDIS DAAC's will continue for the life of the EOSDIS project.

Senator GORE. Thank you very much, Senator Pressler.

Senator Lott.

Senator LOTT. Thank you, Mr. Chairman.

Dr. Fisk, thank you and other members of the panel. You know, there have been some criticisms of the EOS system. You are familiar with these, I am sure. It has been argued that extremely precise instruments launched individually over a long period of time would be just as effective in answering global change and would be better perhaps than this grouping.

How do you respond to that criticism or to that suggestion?

Dr. FISK. I respond the following way. We have had the best science minds in earth science give us advice on how to do this. They do not share that point of view, which says—and it is a very simple argument—that if you are going to build an instrument that has high sensitivity, high resolution, and from that data you want a quantitative understanding, you have to be prepared to know what the atmosphere correction is, because in some cases the atmosphere correction is very significant. And if you want to measure the atmosphere correction you have got to measure the atmosphere

and you have to fly simultaneously the instrument looking at the surface and the instruments looking at the atmosphere.

That drives you into the groupings that we have. That is an argument which the people who are going to use this data, the interdisciplinary scientists who are going to use this data and turn it into understanding, feel strongly about, and we accept their judgment.

Senator LOTT. Is there a chance that the precursor missions and the Earth probes would answer just as many of the global change questions and therefore would preclude the need for the EOS system?

Dr. FISK. No. They will make progress; there is no question about it. I think we will be measuring the same types of parameters with the precursor missions, but one lesson that occurs in all disciplines of science, in earth science and atmospheric and planetary, understanding and models are going to be built on ever-improving resolution and sensitivity.

There are a couple of cases. At the moment, our ability to measure the temperature profile in the atmosphere, which was a big driver for our models, is not driving the models. The observations do not have the resolutions that the models require to make progress. So, one of the reasons that the HIRIS instrument on EOS is a higher resolution, higher sensitivity instrument than flies currently on GOES, is that we want to have a temperature profile which is higher resolution and can drive the models toward better accuracy.

Senator LOTT. I do strongly agree with the Augustine Committee's recommendations or feelings that we need to put a greater effort into all of these various Space Science Programs. But in looking at the budget and the funding it seems to me that we are not putting a lot of money into some of them. I guess I am just looking at the priorities. Precursor missions is, what, $18 million? That is all we have allocated there.

Dr. FISK. No, it is substantially larger.

Senator LOTT. How much do we have for the precursor?

Dr. FISK. Remember, UARS and TOPEX are both major precursor missions.

Senator LOTT. I guess I was talking about the upper atmosphere research satellite.

Dr. FISK. Yes, but it is a $700 million satellite. It simply is on the downslope of its profile. The investment has occurred in previous years.

Senator LOTT. What is the funding for the Mars observer in this year's budget?

Dr. FISK. I brought these people with me to answer these questions. $54 million in 1992.

Senator LOTT. Talk a little bit about the Hubble space telescope and the Gamma Ray Observatory. How are they doing? What are we going to get from, for instance, the Gamma Ray Observatory that is really fundamentally important to what you do?

Dr. FISK. First of all, the Gamma Ray Observatory is doing very well. It was launched, as you know, a couple of weeks ago and we are several days ahead of our checkout period and everything is

working fine. We expect to get into routine science observations in another couple weeks.

What we are probing with GRO is essentially the gamma ray universe. The objects in the universe radiate at various wavelengths various types of radiation, and that radiation tells you about the objects that are out there. In the case of gamma rays, they come from some of the most violent processes, essentially nuclear reactions, occurring in the universe—matter changing into different forms or matter which is accelerating at a high rate of speed as it, for example, falls into a black hole.

This is some of the most energetic known radiation. This is a part of the radiation in the universe that we have essentially not studied very detailed. There have been some previous satellites that have been low-resolution satellites. They have just been probing this information. GRO takes the step in resolution and sensitivity beyond those and essentially gives us information on those processes in the universe.

Remember the philosophy of the great observatories. Hubble is looking at visible light, the kind you can see with your eyes, and ultraviolet, which is very close in radiation; Advanced X-ray Astrophysics Facility, which goes up in 1997–98, looks at the x-rays that come from the universe; GRO looks at gamma rays which are higher energy; and then at some point in the future we will do a space infrared telescope which looks at the infrared radiation.

When you have that constellation of great observatories up, you can see the entire electromagnetic spectrum, all the radiation that comes from the universe, and with resolution and sensitivity beyond anything we have had before. Then you can actually understand the objects that are up there—black holes and quasars and galaxies and stars—the whole bit.

We are essentially in the process of moving astronomy into space in low-Earth orbit. There will be ground-based studies and these will be primarily space-based studies.

Senator LOTT. Thank you, Mr. Chairman.

Senator GORE. Thank you very much, Senator Lott.

Dr. Fisk, last week Admiral Truly discussed the fact that earlier this year the Office of Management and Budget reduced the funding profile for EOS both in fiscal year 1992 and in the out-years. How much was eliminated from NASA's 1992 budget request for EOS and EOSDIS?

Dr. FISK. $124 million.

Senator GORE. $124 million. What effect will this have on the program, specifically the scheduled launch of the first EOS–A platform in 1998 and the initiation of the complete EOS data information system in 1994?

Dr. FISK. It has relatively little impact on those two issues. Let me explain that. Two things happened at the same time. One principal thing happened at the same time. We accepted the recommendation of the payload panel, a painful one to all of us to not fly HIRIS on the first A platform—the High Resolution Imaging Spectrometer.

The issue there was a technical one. The instrument is extremely challenging and we were anxious not to put on this first platform anything that could delay it. We wanted to be able to move out on

it and get it done early, and putting on a high-risk instrument did not seem to be prudent strategy to our scientists and we agreed with that. That offloaded some costs in the early years which can be absorbed within that $124 million.

Now the principal impact of that cut has not been on the launch date of EOS–A. We are in December 1998, and that is only a few months off from where we were before. But where we have paid the price for this cut is what is going to happen to EOS–B and what is going to happen to follow-on EOS–A platforms, not so much in the 1992 budget, but the cuts that were proposed for 1993 and 1994 will make it difficult for us to keep EOS–B on schedule and for us to build the replacement instruments for the follow-on EOS–A platforms.

So, just to summarize, we put the highest priority on maintaining the launch date for EOS–A and EOSDIS.

Senator GORE. Now, to further complicate the funding situation for this program, the House Subcommittee on Space has recommended a further reduction in fiscal year 1992 of $75 million. Can you give us an idea of what effect this additional cut would have on your program?

Dr. FISK. I will be very blunt, and I said it to them as well. It will cripple the program. The worst thing you can do to a program which is doing its best to maintain the earliest possible launch date to get on orbit to produce the measurements is to cut money out of the front end like this. You have to design another program with that level cut.

Senator GORE. That is helpful for the record on which we will base our actions here.

Recently the members of the engineering review panel were appointed and directed to examine options for the EOS Program. Can you give us a sense of the parameters this group is operating under? Is it realistic to assume they will focus on options for launching the first EOS–A platform, or will their focus be solely on later spacecraft design configurations?

Dr. FISK. Let me state the terms of reference as I remember them. We asked them—and obviously a review panel of this caliber is free to look at anything and they are free to look at EOS–A and EOS–B. We did point out to them and they acknowledge and accept that EOS–A is under development at the moment. We are building hardware. It is a new start that has occurred. We are driving for a 1998 launch date.

So, if they have any recommendation on doing something different for EOS–A, it should be a recommendation which satisfies the threshold of being significant improvement in size, return, cost, reliability, or schedule. So, we will show them the EOS–A in detail. Obviously they could have known that since the outset of the program.

But unless they have something dramatic to do different on EOS–A I think that will be the end of the review of that and the primary focus would then be on what to do with EOS–B, which is a wide open issue for all of us at the moment.

You will recall the Augustine panel recommendation which says have the EOS be an evolving program, which is a shorthand notation for saying do not fly all the same instruments on the three

EOS–A series. We need advice on how to make that technology evolve, at the same time preserving the continuity of the measurements, and that will be the thrust of the recommendations.

Senator GORE. So, what you are saying in essence is you will not object if they look at EOS–A, but as a practical matter you expect that they will confine their recommendations to EOS–B?

Dr. FISK. Again, EOS–A has been looked at by the National Research Council. It was looked at by the Augustine panel, in perhaps a more cursory way than the NRC. It was looked at by our payload panel. It has been looked at so many times I would be surprised if somebody had a substantially different way to do this where everybody said, "Gee, that is a really great way to do it."

We think it has been under so much review over the years it would surprise me if there was such an outcome.

Senator GORE. Well, we will be hearing about some of that from our panel that will follow you. I understand that it is possible for you to stay during their testimony; is that correct?

Dr. FISK. Yes.

Senator GORE. I hate to ask you to do that because I know that you have other priorities as well. But we are going to talk about some of these issues with that panel and we might need you to chime in if you want to take exception to some of this.

Dr. FISK. I will raise my hand.

Senator GORE. Since the discussion of alternatives to the basic EOS platform approach seems to exclude the first EOS–A polar platform, what exactly is the status of the development? You say it is underway and all that, but how much money precisely has been invested thus far?

Dr. FISK. We will have to see if we can work that out. When we say we are underway, we mean we literally are letting contracts. You may have seen announcements recently on the contractor for the AIRS instrument and the MODIS–N instruments, and scientists are writing algorithms and developing instruments and so on. But we will try and construct for you the expenditure to date.

[The information referred to follows:]

NASA will have spent approximately $340 million in the Earth Observing System (EOS) through the end of FY 1991. This includes prior year funding for the polar platform in the Space Station Freedom Program, advanced technology development funding in the Office of Space Science and Applications (OSSA) prior to FY 1991, and funds in the FY 1991 OSSA budget for EOS development (following new start approval in the FY 1991 budget process). Of this total, the majority of funds, about $330 million, has been spent to support the design and development of the first EOS–A series spacecraft. Total expenditures on EOS–A through FY 1990 were approximately $145 million, rather than the $115 million cited during the hearing.

Senator GORE. Do you have it offhand there? While you are looking for it, let me just ask this general question.

I do not want the phrasing of my questions to be interpreted as suggesting that we back up and reconsider EOS–A. My impression is that there are an awful lot of extremely critical questions about global climate change that need to be answered very quickly, and if you look at the universe of questions, if you look at the top 20 or 30 questions, the quickest and most cost-effective way to get the answers would, for about two-thirds of them, not be EOS.

But for the remaining one-third, most of those probably cannot be answered without EOS. Some of those are the most critical

questions. If in the two-thirds that can be answered without EOS, we can get the data more quickly, then you have to balance that against the cost you are going to incur on EOS in any event to get the answers to those questions that cannot be answered except with EOS.

It is kind of a difficult tradeoff in many ways. It becomes acute simply because with these budget pressures we have to contemplate the possibility that going forward with EOS effectively precludes spending the money to get some of these other answers quicker and cheaper. That is troubling because the emerging developments in the global climate change research are pointing, it seems to me, toward a repeat of the way the ozone issue evolved—the slow formation of a consensus and then a series of shocks to the system, convincing people who came reluctantly to join the consensus that the problem is real, that indeed we have to move a lot faster than had initially been thought.

If during that evolution we are locked into a program sequence that means that important decisions have to be made years before EOS even flies, then that raises some problems. On the other hand, assuming that the issue evolves in that way, the flexibility on that portion of the budget might conceivably change.

None of these assumptions are hard and fast, although during this set of hearings on fiscal year 1992 budget issues I think it is only prudent for us to assume that the Augustine Committee priorities ought to be followed and that the budget constraints imposed by various committees, including the Appropriations Committee, have to be seen as real and, therefore, we have to be very, very careful in setting our priorities.

All these issues of course are complicated further by the questions I raised in my first round about NASA trying to put into the budget programs that really are not of the high priority category assigned to Mission to Planet Earth by the Augustine Committee.

Dr. FISK. Senator, if I may just respond there, we have tried our best to look at things that ought to be done in advance of EOS that are somehow less expensive and so on. That is, of course, one of the purposes of the Earth Probes Program. That is why there is TRMM and that is where there is TOMS and so on. They were added to fill gaps.

But I think whoever asks the question "What is it that we should do any differently?" You first ought to start from this very massive list of measurements that are going to be made, because I think you are going to find——

Senator GORE. Wait a minute. Say that again.

Dr. FISK. We ought to start from this massive list of measurements that are going to be made and say where are the gaps in that and what improvements can be made in those measurements that we could somehow do earlier.

Senator GORE. I might start in a different place, actually, and I will save a full discussion of this for a later hearing, but I might start by asking what data do we already have that we are not using and how can we learn from it. And the fact is that if you focus first of all on the measurements you are about to make without using the measurements that have already been made—and this is an issue you and I have discussed before——

Dr. FISK. That is a fair statement, and in fact I share your sentiment exactly. That is why EOSDIS has $82 million in 1992, and it is not to build the data system for EOS in 1998.

Senator GORE [continuing]. Compared to $870 million for LIFESAT, that is not fair to compare those two numbers. But I can come up with a whole collection of items that would amount to that sum and larger.

Did you find that number?

Dr. FISK. Our guess is $340 million through 1991, and we will give you an actual for the record.

Senator GORE. $340 million?

Dr. FISK. Through 1991.

Senator GORE. On EOS–A?

Ms. SCHMOLL. Total EOS.

Senator GORE. What about EOS–A?

Ms. SCHMOLL. EOS–A itself is about $115 million.

Senator GORE. Now you can answer this for the record, but if NASA decided that, based on the results of the engineering review panel or if Congress decided that it was in the public interest to change current plans for the EOS–A1 platform, could it be done without losing time and costing significantly more money at this stage?

Dr. FISK. I cannot answer without knowing what the changes would be. If someone said leave two instruments off the EOS–A platform, that is trivial. If someone said provide launch on a launch vehicle that does not exist out of the west coast at the moment and I have to build a launch pad, that is another story.

Senator GORE. That is fair enough. Presumably the instruments and the mix of instruments, all of which has been studied in-depth by extremely qualified people. Nevertheless if that were to change in the near term, seven years before the launch, presumably that could be done without delaying the launch or costing a significant amount of new money.

Now let us wrestle with this issue of the large spacecraft versus small spacecraft. As you know, there are many in the scientific community who believe that in addition to the planned Earth probes, there is a real need to develop several precursor missions to gather data prior to the launch of the first EOS platform.

One such proposal is the CLIMSAT initiative. which is a concept intended to complement rather than replace the EOS platforms. Has NASA considered the possibility of adding CLIMSAT to its list of Earth probes to be flown prior to the launch of EOS?

Dr. FISK. Let me not call it CLIMSAT. The issue is, do you make Earth radiation budget measurements? Do you make aerosol measurements with instruments like SAGE? And you recall that the Academy in its report, the NRC report, also emphasized the need to do Earth radiation budget experiment measurements as not included then in the Earth probes program and should be accommodated. Accordingly, CERES, which is the Earth radiation budget measurement, has been added to the TRIM spacecraft, and that issue I think is now covered and closed.

The issue of whether or not there should be a SAGE also flown on TRIM. Essentially there is a satellite going up in 1997, which is about as fast as you can get something up at the moment, and

the question is what do we add to that to cover those measurements. CERES is added. SAGE would depend on the availability of early funding.

Senator GORE. So, you are opposed to taking some of the EOS instruments that would wait until 1998 to go up, moving them off onto smaller, cheaper satellites early on?

Dr. FISK. No, no. Let me repeat. CERES is the instrument that is on EOS–A, and we would fly it on EOS–A, but we would also fly it earlier on TRIM to do the Earth radiation budget measurements that CLIMSAT recommended and, more importantly, the Academy recommended.

So, I think the important issue is that the measurements are going to be made.

Senator GORE. Are you familiar with—I am confident you are—with the proposal by Jim Hansen, William Rossow, and Inez Fung in Issues in Science and Technology?

Dr. FISK. I read the article when it came out. It has been a while.

Senator GORE. Could you respond for the record to the proposal for two small, inexpensive satellites to take some instruments up much earlier to answer some of the most pressing questions about climate change?

Dr. FISK. I would be happy to respond for the record, but I think what I will also do is give you our recommendations on this issue from our payload panel, which basically was charged with evaluating TRIM.

[The information referred to follows:]

The proposal for the Climate Satellite, or CLIMSAT, involves the flight of a payload of three instruments on spacecraft in both polar and 55-degree inclination orbits. The three proposed instruments are: the Clouds and Earth's Radiant Energy Systems (CERES); Stratospheric Aerosol and Gas Experiment (SAGE III); and the Earth Observing Scanning Polarimeter (EOSP).

NASA has examined the possibility of flying these instruments as part of the joint U.S./Japan Tropical Rainfall Measuring Mission (TRIM) in 1997 to provide the earliest possible flight in a low inclination (35 degrees for TRIM). The results of that review led to the following conclusions:

—CERES is now being planned as part of the TRIM payload, and has also been selected for flight on the first EOS–A series spacecraft.

—The SAGE III instrument would have required substantial near-term resources to meet the TRIM flight schedule; such resources are not available within the NASA budget in FY 1991. Observations by the current SAGE II instrument on the Earth Radiation Budget Satellite (ERBS) continue, with no significant problems.

—EOSP has been selected for flight on the first EOS–A series spacecraft. Its development was judged too risky to be able to support a 1997 launch on TRIM. Fortunately, polarization measurements similar to those planned for EOSP will be provided in a polar orbit on the French Polarization and Directionality of the Earth's Reflectance (POLDER) instrument planned for flight on the Japanese ADEOS spacecraft in 1995.

Assuming the inclusion of these three instruments, it seems unlikely that CLIMSATS of the type proposed could be ready for flight much in advance of the TRIM Earth Probes mission in 1997, meaning that their value in providing earlier results on critical questions of global change would be substantially diminished. NASA believes that the planned program of observations by EOS, Earth Probes, and foreign cooperative missions, provides the most prudent means of acquiring the desired observations as rapidly as possible.

Senator GORE. Very good. But let me again repeat that this is intended to complement EOS and not to compete with it. I have not reached a conclusion on that. I am attracted to the idea, but I would like to see your in-depth response as soon as possible.

Dr. FISK. I would be happy to do that. I think again one of the things we ought to be sure—all this happens when people propose additions, alternatives and things to this—is that they do deal with the experts on this issue, the people who advise us on how to do this, and these ideas should be evaluated there more than by NASA headquarters.

Senator GORE. Given the inherent difficulties that large missions typically encounter, such as funding reductions over their long life and technical delays, does it not make sense to place a little more emphasis on these smaller satellites as a hedge against problems that could develop in the larger program?

Dr. FISK. Well, let me make one point that I think is very important. You know, EOS–A is no longer all that large or all that forbidding a satellite. With the removal of the high-risk instrument from this satellite, there is no technology demand on this thing that cannot be done with existing technology. In fact, the data rates on EOS–A—I looked them up this morning—the average data rate on LANDSAT is 15 megabits a second; the average data rate on EOS–A without high risk is 17 megabits a second.

Senator GORE. Again, 95 percent of the images from LANDSAT have never fired a single neuron in a single human brain.

Dr. FISK. We will not let that happen on EOS. But I think the point I want to make is that we have taken some actions to make the EOS–A satellite a very straightforward satellite to build. I do not view it as a technical challenge. The only issue you should hedge yourself against is perhaps launch failure. That is the issue that you can debate endlessly about the best strategy.

But the difficulty you always face, of course, is that if you try and do these on multiple satellites then of course you have to count on success of multiple launches. Actually, the probability is probably lower on a series of launches being successful than on one launch being successful.

Senator GORE. But the damage to the overall effort is much less and flexibility for recovery is much greater.

Dr. FISK. That is fair.

Senator GORE. Much of the debate about large versus small platforms in polar orbit focuses on the fact that there is currently no west coast launch site for Atlas–IIAS launch vehicles. It is my understanding that the Air Force is now actively reviewing the possibility of developing such a site. If such a facility were developed and available for use by NASA for polar-orbiting launches, how would that affect your planning for EOS?

Dr. FISK. The principal thing it would do is it would finally give us options for EOS–B that we could readily consider. At the moment all of us would be very comfortable breaking up the EOS–B satellite into a series of moderate-sized satellites. There are a lot of compelling reasons to do so.

However, today I have no launch vehicle.

Senator GORE. Could you give us a cost comparison of Titan–IV launches as currently planned for the EOS platforms versus the necessary number of Atlas–IIAS launchers?

Dr. FISK. I will have to answer for the record, but I would be happy to do so.

Senator GORE. That would be fine.

[The information referred to follows:]

Dividing the payload planned on the first spacecraft in the EOS–A series, currently planned for launch on a Titan–IV, would result in a substantial loss of scientific capability, by sacrificing the simultaneity of measurements needed to satisfy the objectives of the U.S. Global Change Research Program. We are currently studying the possibility of using smaller spacecraft for flying the instruments in the EOS–B series, for which the scientific requirements for simultaneity are not as rigorous (i.e., the synergism is critical for sets of instruments, not the majority of the payload).

According to a May 1990 spacecraft sizing study prepared by the Goddard Space Flight Center, dividing the instruments planned for flight on the EOS spacecraft into smaller components capable of flight on an Atlas–IIAS or Delta II could increase the number of required program launches by a factor of 3 (from 6 to 18) or 6 (from 6 to 36) respectively. Estimates for launch of a Titan–IV range between $160 to $170 million in FY 1990 dollars.

Although discussions to date have focused upon comparisons of Titan–IV and Atlas–IIAS capabilities for EOS, any proposed change in the launch vehicle for EOS payloads would likely involve consideration of a wider range of launch vehicle choices. If such a change were contemplated, NASA would, in accordance with the Launch Services Purchase Act of 1990, conduct a competitive procurement for these launch services.

At this time, the USAF has included the EOS Titan–IV requirements within their existing baseline capacity and long-range planning. In addition, NASA is funding an upgrade of the existing Delta facility at the Western Test Range (WTR) to meet ongoing agency launch requirements for Delta II's. At this time, there is no Atlas–IIAS capability available at WTR. However, the USAF is in the process of formulating an acquisition to fly an Atlas-class medium launch vehicle from WTR. An initial launch capability may be needed as early as 1994. Costs associated with developing this capability are being developed by the USAF and are not included in our cost estimate for an Atlas–IIAS. Moreover, it is important to note that these estimates address only the costs of the launch services for the EOS mission. Not included are potential additional costs associated with the use of a greater number of satellites, increased data processing and spacecraft tracking requirements, and changes in the spacecraft integration process.

Senator GORE. I have a number of other questions, but I am going to wait for a third round and I want to recognize Senator Pressler.

Senator PRESSLER. Mr. Chairman, I just want to do a couple more questions here that do seem a little parochial because they are about the EROS data center in Sioux Falls, but they have a broader national view.

I guess I am going to ask these same questions to the next panel also, although I have to go off to a skull session on the Moynihan amendment here in about a minute. I will try to get back.

But let me ask you, since the EOS Data and Information System is a crucial element in NASA's Earth Observing System, what progress has been made toward designing and building the EOS Data and Information System?

Dr. FISK. Of course it is a major effort for us at the moment, and there are two main thrusts. There is, as you noted earlier, the preparation of requests for proposal which is essentially a design of the EOSDIS to which contractors then will respond, and we expect to have that out in the July timeframe.

But concurrently with that is the development of the version 0 data system, which includes our various pathfinder data sets. As you know, we share Senator Gore's and others' sentiment on this, that there exists a fair amount of earth science data which has been underutilized, and that there is a motivation here for converting those data sets into usable geophysical parameters and circulating them to the community. We are actively doing that.

Senator PRESSLER. Now the U.S. Geological Survey's EROS Data Center located in Sioux Falls, SD, will participate in EOSDIS. What role do you envision the EROS Data Center having in the EOSDIS?

Dr. FISK. Well, it is a very central role in the sense that there are seven DAAC's, Distributed Active Archive Centers—I think I have that right—and Sioux Falls would be the second-largest. Goddard would be the largest, and it is the one that is devoted to land surface data. Of course, that builds on the heritage of EROS and doing the Landsat data.

Senator PRESSLER. I am told there is a lot of Landsat data or a decade of Landsat data that is unreadable, that has never been looked at. What is the applicability of the nearly 20 years of Landsat data to EOS and what are we going to do with the Landsat data we have already accumulated that could really give us a 20-year headstart in understanding global change?

Dr. FISK. Again, let us be optimistic and say somehow we can get access to this data at a reasonable price. Whenever you do global change studies you are looking for long-term changes, and the thing that the Landsat data gives to you is essentially the baseline against which future changes can be measured.

So, to the extent to which we can get access to selected parts of that Landsat data and build a sort of consensus on the baseline against which we will measure change, that is perhaps its most valuable role.

Senator PRESSLER. What are your plans for the centers that are participating in the EOSDIS to participate in these pathfinder programs?

Dr. FISK. Of course the DAAC's are built around specialties, Goddard being climate, Langley being upper atmosphere, Marshall being hydrology, and so on, while the pathfinder activity essentially will be directed at dealing with pathfinder data sets that are in their specialty.

Senator PRESSLER. Thank you. I may have some more questions for the record, and I would like to submit these same questions for the next panel. I am going to have to go to a meeting and try to come back. But I am very glad, Mr. Chairman, we will be holding a hearing on the management of the data.

It is kind of ironic that perhaps with all the efforts to collect it that we are not using a good deal that we presently have in our possession. Thank you, Mr. Chairman.

Senator GORE. Thank you, Senator Pressler. We certainly will be spending a lot of time on that issue. I share your feeling that it is a priority.

Let me ask you about airborne sensors. In many instances there are much quicker ways of gathering data on various parts of the global environmental system, including the use of aircraft carrying sensors, flying regular missions over particular areas. NASA's fiscal year 1992 budget requests $5 million for airborne sensors. Can you discuss what this proposal entails?

Dr. FISK. I can. Please bear in mind, of course, there is a much larger portion of our budget that is devoted to airborne activities than that $5 million. We have an ongoing aircraft program in earth science which is in the $20 to $30 million range.

This $5 million in the 1992 budget is to look at a new initiative of remotely piloted aircraft and basically, you know, there is an option to fly aircraft at altitudes and for durations which would be difficult to do with manned vehicles and explore that as a possibility. That would be, obviously, an augmentation of the very large and active aircraft program we already maintain.

Senator GORE. In other words, this is not really for airborne sensors. This is to explore the development of a new kind of aircraft.

Dr. FISK. Well, a new kind of aircraft and their sensors would have to be designed accordingly because they are quite small.

Senator GORE. That sounds like it might take as long as the EOS platforms.

Dr. FISK. I do not offhand know how long it will take.

Senator GORE. Do you have an estimate?

Dr. FISK. Not off the top of my head. This is something that has been directed by our engineering panel as well as part of their terms of reference to evaluate the significance of the program.

Senator GORE. Have you talked with Sherry Rowland about this?

Dr. FISK. No, I have not.

Senator GORE. Sherwood Rowland, as you know, is one of several distinguished scientists who are leading experts in the world on the ozone depletion program. He and Robert Watson and some others testified here last week. Dr. Rowland, who is among those whose judgment I trust a great deal in these areas, seems to feel that there are some very inexpensive atmospheric measurements that can be made with airborne sensors very quickly that would yield extremely valuable data helpful to us in filling in some blank spots in our effort to understand what is happening in the dynamics of the global atmosphere.

I would encourage you, Dr. Fisk, to call him up and ask him about that, and instead of focusing on an experimental vehicle that may not fly until the next century let us get some of these instruments up there as quickly as possible to fill in some of these most glaring gaps in the data.

Dr. FISK. I would be happy to. Please bear in mind that we do in fact routinely make measurements of the atmosphere and the troposphere with aircraft. We probably have 100 flights a year with aircraft, and the question is if there is instrumentation we do not currently fly of course we would be happy to have our science committee look at it.

Senator GORE. Well, I have been out there and been on at least one of those planes. I know that your folks do a great job on that. But there are some gaps that need to be explored very quickly. I will not get into it here, but we will pursue this later.

In connection with this new RPV, what altitudes are you looking at and what kind of development budget are you looking at?

Dr. FISK. I am sorry, I do not know. High is what it says here. The budget runout that is currently in the budget—this is full disclosure, so we do not hide it. It is an $80 million runout in our budget, at $15 and $20 million, leveling off to a $20 million a year effort.

But again I think there is a considerable amount of controversy as to the merit of this program. This is clearly a case where both our science community and our engineering review needs to evalu-

ate it, so I think the significant number is the 1992 number to determine the feasibility and its importance for the science program.

Senator GORE. Are you current on what the military has in this category?

Dr. FISK. Personally I am not.

Senator GORE. Well, I would encourage you to do that because we already have some systems that may perfectly match the contours of what NASA is about to attempt to develop. I cannot say that that is the case because I do not know what the contours are, but I do know about the military systems that are out there.

As you know, I pushed an idea which was eventually adopted by the Congress last year to create a strategic environmental research and development council, and we are actively looking for ways to place instruments on military missions that can provide data to fill in some of these gaps.

I will ask my staff to follow up with yours and the Armed Services Committee staff, but in the meantime I would encourage either you or some of your people to call up Sherry Rowland, Bob Watson——

Dr. FISK. I do not have to call Bob.

Senator GORE. You do not have to call Bob; he works for you. But call up Dr. Rowland and ask him.

Dr. FISK. Bob has the lead in our organization on this.

Senator GORE. He does not always have the authority to make the decisions, though.

Dr. FISK. That is probably wise. [Laughter.]

Senator GORE. We could debate that for some time, Dr. Fisk. I would relish the opportunity to debate that, but it might not be the best use of our time today.

How many people with specialized skills will eventually be needed to handle EOS and EOS data? Are we planning in some way to have them on hand?

Dr. FISK. Ironically, the one chart I do not think I brought that I was going to show you is the number of investigators we anticipate having within EOS.

Senator GORE. If you can provide that for the record.

Dr. FISK. I will.

[The information referred to follows:]

Activities associated with NASA's Mission to Planet Earth Program, including the EOS program, will require an approximate doubling of the earth science community supported by NASA. Early EOS science efforts alone will increase the number of earth science investigators directly supported by NASA from approximately 700 to 1,200. Included in this increase is a nearly 30-percent increase in the number of universities and other institutions which are connected with the NASA Earth Science Program. Many of these scientists are already working on the early phases of EOS data analysis and instrument development. Several thousand additional personnel, located within NASA and at research and aerospace engineering locations around the country, will be needed to assist in interpreting and processing the data, developing the EOS Date and Information System, EOS instruments and spacecraft, and eventually operating these systems.

Dr. FISK. We know how many we need. The challenge is going to be providing them. I think there are two things that will occur here. The earth science community is, of course, very large and the issue is having people who are not now involved in space, and the use of space data, become involved. So, there is a fair sea of folks out there that we can draw on.

But also built into the EOS Program is a graduate fellowship program to try and stimulate, and we will be funding at about 100 or 150 graduate students per year, which will be in part the next generation over the long term of earth scientists.

Senator GORE. What have you done to convert environmental data collected through classified missions?

Dr. FISK. Let me bring Dr. Tilford up.

Dr. TILFORD. The area where we have been working most in utilizing data that was collected under classified means is in the area of gravity fields and geodynamics kind of measurements. There has been a significant change in making some of this data available for the past few years. We have a continuing dialog with our colleagues both through the government and through the scientific community, the National Academy of Sciences, of making additional data available.

I think that is moving along in the right direction. Sometimes I wish the rate were a little bit faster.

[The information referred to follows:]

NASA has been working closely with the Department of Defense (DOD) on making data from DOD missions available to the research community. These efforts have focused on data from two missions:

—*Geodetic Satellite (Geosat).* The Navy's Geosat spacecraft operated from 1985–90 using a single-beam radar altimeter to make measurements of ocean topography, wind waves, gravity fields, mesoscale ocean eddies, and sea-ice field coverage. NASA has acquired data from the later years of this mission for ocean research. Some of this data remains classified, and NASA is working with the DOD to gain access to data from the first years of the mission.

—The *Special Sensor Microwave/Imager (SSM/I)* has flown on Defense Meteorological Satellite Program (DMSP) spacecraft since 1987, providing important data on precipitation, clouds, water vapor, wind speed over the ocean, and sea ice. The data is archived at NASA's Marshall Space Flight Center and the National Snow and Ice Data Center in Colorado where it has been available to NASA for use in hydrology and sea-ice studies. More recently, NASA created WetNet, a computerized, interactive data network linking selected researchers around the world studying hydrology. WetNet generates products (such as atmospheric water vapor concentrations) and algorithms for researchers in real time, with daily access beginning in 1990 to the data from the SSM/I instrument. WetNet also serves as a small prototype data system for EOSDIS.

Ongoing discussions continue between NASA and the DOD to make available other known satellite and ground-based data that are currently classified.

Senator GORE. Thank you. If you can supplement that response for the record, we would appreciate it. We put $1 million in the budget last year specifically for this purpose. I will just say again there is an enormous amount of data currently classified which could fill in a lot of gaps that we need to understand quickly.

One of them, for example, is looking at ice measurements in the Arctic. We talked a little informally before this hearing that the U.S. Navy has been extremely cooperative in configuring and releasing data collected in the top secret category by nuclear submarines moving under the icecap for analysis by ice scientists, which were assembled under the auspices of this subcommittee, and we encouraged a dialog between the ice scientists and the nuclear Navy.

It has been extremely productive. There are comparable dialogs which we want to encourage and facilitate between NASA and DOD and other parts of the Federal Government collecting classified data, which in many cases completely overlaps data sets that you are planning to collect 10 years from now.

We ought to go ahead and work out the protocols for getting that data into the white, scrubbed for national security data points that should not be released, and start analyzing it vigorously.

Now, on EOSDIS—again we are going to have a special hearing so I will keep this brief—one of the key components of EOS is, of course, the data and information system. It is my understanding that NASA has once again delayed the request for proposal for EOSDIS. Is that correct?

Dr. FISK. There is a short delay to July, yes. There were two reasons for it. I can go into them. I also do not anticipate that there will be a significant delay in awarding the contract, which is the more serious issue.

Senator GORE. When do you expect the contract to be issued to begin development of EOSDIS?

Dr. TILFORD. We expect to issue the RFP, as Dr. Fisk indicated earlier, at the end of July. We hope to make a final selection approximately 1 year later. But we would like to have a letter contract sometime in midsummer of next year. It is extremely long and very expensive and has many, many implications, so we would hope to have a letter contract, I believe, by early July of next year.

Dr. FISK. One comment I think is important. This is a selection that we are taking extraordinarily seriously for a couple of reasons. First of all, we have to get the right contractor. But, you know, the various bidders on this contract or potential bidders are investing a considerable amount of resources. This is something like the ATF for the data system people.

So, part of our precaution here on this RFP has been so there can be no claims of procedural error in awarding this contract. We are being extremely cautious to make sure that there are no claims because those, of course, result in more delays.

Senator GORE. Enough said. I understand. But, just to pursue this for a moment, increasingly I hear discussions about changes in how EOSDIS is being described and presented. For example, I now hear talk about a core system. What is the core system and does this represent a significant change from the EOSDIS proposal that we heard about last year?

Dr. FISK. There is no significant change. Let me allow Dr. Tilford to answer in detail on this, but there is no significant change, and whatever change continually occur on this are our attempts to be absolutely responsive to the users who guide us on this.

Senator GORE. You will also try to be responsive to OMB's efforts to scale back the program, will you not?

Dr. FISK. Reluctantly.

Senator GORE. To what extent are these changes ones you have made reluctantly?

Dr. FISK. No, these changes are not driven by budget issues.

Dr. TILFORD. Senator, the major initial delay in this was taking the advice of the community first, but also the Japanese came forward and suggested that instead of starting the EOSDIS in an operational mode—with the launch of EOS in late 1998—they suggested why don't we use the ADEOS and TRMM missions as precursors in terms of using the DAAC's to actually distribute data from ADEOS and TRMM.

This was a very aggressive suggestion for them. We accepted that as something we should do. So much of the delay or some of the delay in changing the RFP was to go back and incorporate the concept of putting these earlier missions in as precursor missions such that we could actually use EOSDIS to provide data to the community through these two precursor missions.

So, what we were trying to do is do it faster and in the meantime slow it down a little bit up front.

Senator GORE. Is that the core system? What is the core system?

Dr. TILFORD. Essentially I think it is better to talk about the version 0, version 1, and version 2.

Senator GORE. Have you heard the phrase "core system"?

Dr. TILFORD. To be honest, Senator, I have heard so many different phrases on the EOSDIS, and the acronyms are that long. I have to apologize that I do not know what the core system is.

Senator GORE. You do not, really?

Dr. TILFORD. But I will report back to you. I know what the version 0 system is, I know what the version 1 system is.

Senator GORE. Dr. Fisk, have you heard the phrase core system?

Dr. FISK. I have heard the phrase. I know the phrase "core system."

Senator GORE. What does it mean?

Dr. FISK. I am not sure I know what it is in this context.

Senator GORE. Wait a minute. Hold on. Wait just a minute. I want to know what the core system is, please.

Dr. FISK. We will give you a specific project definition of "core system." I will tell you what I think it is, but I would prefer to answer for the record.

The issue is when you do a selection you have to define precisely what it is that the contractor is bidding. You write an RFP. You say I want you to bid this thing. I believe that the term in this expression means that they are bidding the core system. That is what we are asking them to be able to bid.

Senator GORE. In your further response for the record I would like to know what has been eliminated from the system in order to get the core system.

Dr. FISK. Time out. There has been nothing eliminated from EOSDIS that we have been telling you differently about. The only issue when you write a contract like this, you have to bid something specific, and then you say there will be task orders for the following items that will come later. But you want them to bid something specific, so you can evaluate them.

But we have not made any reductions in the capability of EOSDIS.

Senator GORE. Do not take this the wrong way, but there are so many times when I have heard NASA witnesses come here, when OMB pressures or other pressures have resulted in what looked to be significant changes in a program, and we get absolute assurances that nothing has been left out, all the capabilities remain. Then later on we find out that actually there have been some significant changes.

So, in your response for the record if you would please specify exactly what is not included in the core system that was included in the EOSDIS presentation you made to the committee last year.

Dr. FISK. I will be happy to do that, but I will also make sure that you understand what is in EOSDIS. That is the important issue, not what is in the RFP but what is in the DIS.

Senator GORE. If it not in the RFP, who is going to do it?

Dr. FISK. Well, for example, version 0 is not in the RFP. It is being done now. That is part of EOSDIS. The algorithm development is not in the core system, but that will be done by the experimenters so that is part of EOSDIS and so on.

[The information referred to follows:]

The EOSDIS Core System (ECS) will provide planning and scheduling, data processing, and data management capabilities for the EOS mission and it will provide the overall system structure and standards needed to ensure the end-to-end operability of the many elements of the overall EOSDIS. The ECS is conceived as a hierarchy of segments, elements, subsystems, and components. The current design proposed for the core system is essentially the same which has been discussed over the last several years.

At present, NASA is preparing a Request for Proposals (RFP) from industry to support development of the overall EOSDIS. This procurement is known as the EOSDIS Core System (ECS) procurement, from which the term "core system" has been derived. The ECS includes the hardware, software, engineering, and operations required to implement the following EOSDIS functions: (1) archival and distribution of all NASA earth science data acquired through 2002; (2) product generation of EOSDIS Distributed Active Archive Centers (DAAC's) of all standard data products generated from the EOS–A1 spacecraft; (3) information management services for all EOSDIS holdings; (4) EOSDIS mission/science network to interconnect all EOSDIS facilities, elements of the science community, and international data systems, in support of product generation; and (5) command and control of the EOS–A1 spacecraft and payload except for those functions provided by NASA's Office of Space Operations, and not including the JPL and foreign partner instrument control facilities.

The EOS Data and Information System includes elements which are not included as part of the ECS procurement which are critical to system and program success. The budgets for EOSDIS and other parts of the EOS Program, where appropriate, provide for a balanced investment in these non-ECS elements as well as those in the EOS Core System. Some of these elements, not included in the ECS procurement, include: (1) most version O activities underway now and running through 1996, including preliminary processing of existing and near-term data sets (such as pathfinder data sets); (2) science computing facilities at EOS investigators' sites; (3) the network providing general, open connectivity to the full EOSDIS user community, eventually through the National Research and Education Network (NREN); (4) some preliminary support for the EOSDIS DAAC's, including buildings, near-term site support, and user support services; (5) development of algorithms to process EOS data into standard products including the implementation of these algorithms as computer software; and, (6) support for a variety of related activities, such as the Consortium for International Earth Science Information Network (CIESIN) and the production of data by all other NASA earth science missions after launch.

Senator GORE. But that is not part of the core system, version 0?

Dr. FISK. That is correct. But that does not mean it is not going to happen. It just means the core system is something to bid against.

Dr. TILFORD. And there has been no change in that.

Senator GORE. I want to be convinced. Let me say that I appreciate your willingness to answer all these questions and others that we are posing for the record and your willingness to stay a little bit longer and listen to this panel and help us respond to what they have to say.

But we are going to move now to this panel. I appreciate your appearance here. Dr. Berrien Moore, Dr. James Baker, Dr. Gordon MacDonald, if the three of you would come forward.

Dr. Berrien Moore III is Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire; Dr. D. James Baker is President of the Joint Oceanographic Institutions here in Washington; Dr. Gordon J. MacDonald is with the Institute on Global Conflict and Cooperation at the University of California in San Diego.

Thank you for your patience, gentlemen, in waiting through the long testimony that has just concluded. We very much look forward to the statements that you have. Without objection, the full prepared text will be included in the record. You are free to present that portion of it that you wish to, focusing on what you think is the most important for the subcommittee to understand.

I am really glad you are all here. Dr. Moore, if you would lead off the panel, I would appreciate it.

STATEMENT OF DR. BERRIEN MOORE III, DIRECTOR, INSTITUTE FOR THE STUDY OF EARTH, OCEANS, AND SPACE, UNIVERSITY OF NEW HAMPSHIRE

Dr. MOORE. Again, rather than go through my full text I think I will just enter that, as you suggest, for the record, including the attachments which I brought down that are associated with this statement. These are the letters from the payload panel for EOS–A which I chaired that were written to Dr. Fisk over about a 1-year period. There were three letters that came forward with a recommendation.

There are a couple of points that I wanted to note or have you note in my testimony. One of those dealt with the fact that one of the central aspects of the Mission to Planet Earth is this issue of a long-term data record. I think you know perhaps as well as anyone in this room the importance of long-term records.

If we tried to think about a world in which we wanted a CO_2 debate without the ice core record or the Keeling Moana Loa record, it would just be impossible. In fact, not to divert, but I was reading on the plane coming down here Scientific American's this month's profile of Governor Sununu, and one of the comments that Governor Sununu makes in this profile is that how it can be possible to see a fossil fuel 5 billion metric-ton-per-year signal when the biosphere is exchanging 100 billion metric tons of carbon every year. And we only know that exchange within about 20 percent, so clearly the fossil fuel signal would be lost in the noise.

As we that have been working on this problem for some time all know, if you look at the ice core record, the atmosphere was relatively constant with respect to CO_2 and it begins to increase at about 1740, and around 1860 it starts to increase more rapidly. So, it is clearly a perturbation problem. But without that, without that long-term record, you would be confronted by, I think, such a comment or such a comment would be valid.

Senator GORE. Your conclusion was that his comment ultimately is invalid; correct?

Dr. MOORE. It is obviously invalid because the long-term historic record——

Senator GORE. I just wanted to pin that down for the record.

Dr. MOORE. In the same way, the Earth-observing system is to establish a long-term scientific and credible record, it is my posi-

tion that after 15 years of Mission to Planet Earth I do not think it is going to stop. The reason for this is that if we have an ozone hole today because of too many CFC's in the atmosphere, then we are going to have one tomorrow because the residence time of CFC's in the atmosphere is long. If we could go to a constant emissions on CO_2, which would be a great thing to do, the atmosphere concentration will still increase, and therefore we are going to be confronted with a number of global change problems that are not going to go away.

I think that we have to look at EOS in that context. So, when we start thinking of ways to ensure the development of a long-term record—and this is one of the points that I have tried to bring out—and when I start thinking about the multiple spacecraft and implementing them with a few free-fliers to make some pertinent observations, whereas that is a valuable addition, I do not see it as laying the groundwork for a required long-term monitoring system.

Senator GORE. Dr. Moore, if I could interject here at this point, I do not disagree with any of that. But we are not through studying acid rain either. And yet the Congress wrestled with and made some critical decisions last year about how to deal with that problem and committed the country to very difficult and expensive and controversial policy changes which I supported.

But the research study which was designed to inform those policy decisions was not available. It is nice to have it afterward, but the decisions on global climate change may well be confronted—some of them are being confronted now—before this effort yields information that can be of use to us in fashioning those responses accordingly.

So, it is not just a scientific data-gathering effort to create a long-term record for reference. It needs to yield data as quickly as possible.

Dr. MOORE. Let me see if I can address this in three ways. First of all, What can we do right now that would be relevant to the policy debate today?

Senator GORE. Or within the next few years.

Dr. MOORE. Then let me address what would be relevant say in the middle part of this decade. And then I think I have addressed the longer term issue.

Today we have great uncertainty, again as you know, about the role of the biosphere in the carbon cycle. One of the central questions is what is the rate of global deforestation. It is now apparent to many of us that you cannot get that information from the AVHRR satellite. The pixel, the resolution, spatial resolution, is too coarse. Therefore, we start looking at where is that data. Well, the data is in the Landsat record. So, is there a way today of making available the Landsat record?

I am sure that within 2 to 3 years we could get a historic baseline and perhaps a 1991 data point on what the rate of deforestation is throughout the entire tropics.

Senator GORE. Of course, you know that because—and I want to give NOAA credit for changing their pricing policy on Landsat. We pushed them to do that, and finally they have done it. But essen-

tially those pictures are not being taken now until there is a specific order from a commercial customer.

So, if you are relying on that record nobody is placing the orders. Nobody is telling them to turn the satellite on. That is an example, really, of a relatively low-cost data acquisition effort that could be made now that is not being made, but indeed changes to the land surface area of the Earth are critical to the answering of lots of questions—deforestation, as you say, Albedo changes, others.

We could turn those cameras on and collect that data, configure it, use it, and analyze it. But we are not doing that because so much of the focus is on something that is going to happen 10 years from now. Go ahead.

Dr. MOORE. Well, first of all I think we have to recognize that that is something that I believe could be done today. I think that the amount of resources that we would be asking to establish a scientifically valid sampling approach are not extreme, but it is something that could happen today.

I think that NASA has been responsive in the Earth probes line. For instance, for the ozone monitoring I read a Hansen article—in fact, I read it a number of times even before it was printed and offered suggestions. If I recall correctly, the small climate satellite involved four instruments really—the aerosol-measuring instrument that in fact the Goddard Institute of Space Sciences is developing, EOS–P, was one of the instruments, and the payload panel recommended that that fly on the A platform. I will come back to that in a moment.

Another was SAGE–3, which is developed at Langley Research Center and continues the SAGE–1, SAGE–2 measurements. And we recommended SAGE–3 to an early flight—that is, to fly in advance of the A payload. Another was CERES, also out of Langley, and that was slated for space station, but with the descoping of space station the attached payloads are off. CERES was one of the high-priority instruments recommended for A and I guess Dr. Fisk said that that will be added to the TRMM package for 1996–97.

So, in a sense a major portion of the small climate satellite, NASA is responding to or the payload panel recommended those instruments not as a small climate satellite but as perhaps flying on TRMM would be an approach.

The French and the Russians are doing an earth radiation budget so in some sense the fourth item will also be made available. So, I think that there are some things, by modifying the probes line that could be done in the near term or in this middle timeframe.

I would like to mention something else that just occurred to me. Jim Tucker from the Goddard Space Flight Institute, Space Flight Center, was up at New Hampshire on Monday and we spent a long time working on some of these questions of what we could do today, and he told me that within a year they will have reprocessed all of the AVHRR data for a 10-year period, and it will be on optical disk available to the research community. So, I think that is kind of an individual effort within this PATHFINDER data set that should not go unnoticed.

Let me just make a comment. There are a couple of other things that I wanted to point to. The issue of the large EOS payload and it being so distant, that is what led us on the payload panel to do

something particularly pleasant, speaking personally from my own research, and that was to delay the HIRIS. I thought it was a real sacrifice. I worried a great deal about that because it was extremely valuable.

In some sense it carries on for the thematic mapper of Landsat but much higher resolution. So, with offloading of the HIRIS I think it has brought the EOS–A payload to well within kind of a historic trend with respect to weight volume and data rate of Earth observation. And in a way what that has done is that it has not removed the need; in other words, we just simply felt that for the overall good of the observations that HIRIS had to be sacrificed. Note that this action actually casts even more importance on the Landsat series, because now if we do not have the HIRIS coming downstream and if we do not have Landsat data available to the scientific community, including the follow-on, then we really will have in some sense lost our understanding of the ecological processes that are being altered by climate change, by tropospheric ozone, by the alteration in the nitrogen-sulfur cycles that we know are occurring. Eastern Europe is just the far end of the spectrum.

The final thing I wanted to mention is we did think about the question of are there some ways to make the program more resilient. We asked the question initially what would happen if certain instruments are not available. What do we do? Suppose we have a technological problem with one of the instruments. So, in one of the letters to Dr. Fisk—I think is the September letter, the last letter we wrote him—it is not something we wanted to say because you feel like that it could be a self- fulfilling prophecy, but we ranked the instruments, of which ones you had to go with and which ones you had to wait on or which ones you could sacrifice if there were a technological problem.

But I want to caution this whole budget process that if we go in and start descoping further the A payload and start offloading some of the observations, I think we will really be doing an injustice.

We took two questions. What is the role of clouds in the climate cycle, in the physical climate system, and what are the characteristics of the carbon cycle? We took those two questions to prioritize the observations. There are a lot of other questions you could ask, but if it did not meet those two questions it more or less fell by the wayside.

I think that that process was valid. It is at least documented. So, I would like to call attention to that in the record.

The other aspect, I think we have squeezed the instrument package down about as far as would be wise. You can ask, is there a more resilient way we could implement it, maybe because of concern of catastrophic failure on launch. Then I start worrying about the fact that we have then to break it perhaps into three Atlases—in other words, one large payload becomes three Atlas payloads. Now, in order to have the simultaneity which is essentially—it is not just an addition or something we would like; I think it is essential—then we are going to have to fly those in formation.

That means that those three spacecraft are going to have to maintain not only ground track; they are going to have to maintain formation, which means an orbit-adjusting maneuver about every

3 or 4 days as opposed to once a year. And now I feel like rather than making the program more resilient I am making it more complex.

And this is perhaps a stretch on the example, but if I look at some of the success of the Japanese automobile manufacturers, it is that rather than add an infinite number of trinkets or some new type of gizmo every few minutes, they try to make the automobile, in some sense, as simple as possible. I think that we have to ask the same question. Just because the platform is large does not mean it is complicated. I start thinking of formation flying as something that is complicated.

Finally, I would like to agree with the Senator's comments about the importance of the Augustine panel's recommendations. I feel like that is a very valuable document and should serve to guide NASA and in fact the Nation, which was well served by this panel.

[The prepared statement of Dr. Moore follows:]

PREPARED STATEMENT OF DR. BERRIEN MOORE III

I am delighted to discuss the Space Science and Applications Program with NASA, and, in this context, to focus upon the Earth Observing System (EOS). I am delighted to engage in this discussion not only because I have been closely associated with the program and hence I will be discussing, in part, my own interests, but also because I sense that there exists a certain degree of misunderstanding about NASA's scientific program generally and EOS in particular.

As stated, I am associated in a variety of ways with the scientific program in NASA. I am the Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. Within this institute, there are a variety of scientific activities supported by NASA. For instance, we are the lead American institution for the Imaging Compton Telescope (COMPTEL) recently launched on the Gamma Ray Observatory. More personally, I am the principal investigator on an EOS Interdisciplinary Science Investigation, and I serve on the Science Executive Committee (SEC) of the EOS Investigator Working Group. (The IWG is composed of 60 members which includes the Interdisciplinary Principal Investigators and their U.S. counterparts, the Instrument Principal Investigators and the Facility Team Leaders.) In this capacity, I chair the Payload Advisory Panel which presents to NASA the views of the EOS/IWG on which instruments to fly on the EOS mission, in what configuration, and when. Finally, I serve on the NASA Advisory Council and chair the Space Science Applications Advisory Committee. Since 1988, I have been a member of the National Academy of Sciences Global Change Committee.

Today, I shall be speaking for myself.

I would like to make three points. First, I would like to discuss briefly the report of the Advisory Committee on the Future of the U.S. Space Program and the role of science within NASA, including Missions to and from Planet Earth. Second, I would like to review the status of the EOS mission and focus upon the question of payload and implementation plans. Finally, I would like to close with some personal comments on the FY 1992 budget and the political climate surrounding EOS.

1. The Advisory Committee on the Future of the U.S. Space Program properly recognized the priority role of science within NASA, and they called a continuation of support of the space science program "at or somewhat above its present fraction of NASA's budget." (Page 5 of the report.) This is the so-called 20-percent guideline. They also discussed two overarching national initiatives that NASA would lead: Mission to Planet Earth and Mission from Planet Earth. These initiatives clearly go beyond the core space science program and will, if pursued, place requirements on NASA's scientific program that will require additional funding. It should come as no surprise, then, that the budget of the Office of Space Science and Applications will exceed the traditional guideline if NASA pursues either Mission to or from Planet Earth. Finally, regarding these two overarching national initiatives, I would like to observe that (a) the Commission clearly stated that there was an urgency to pursue Mission to Planet Earth; whereas (b) Mission from Planet Earth, which is the primary rationale for Space Station Freedom, should be "configured to an open-ended schedule, tailored to match the availability of funds." (See page 28 of the report.)

2. Mission to Planet Earth is a costly, long-term affair. The Earth Observing System is planned for 15 years; however, I do not think that any of us believe that we will be able to stop monitoring the planet or being concerned about global change after 15 years. As you well know, even if carbon dioxide emissions were held constant at current levels, the atmospheric concentration would continue to rise. If we have a stratospheric ozone hole over the South Pole today because of the presence of CFC's, then, because of the long lifetime of CFC's in the atmosphere, we will have an ozone hole for quite some time even if no further CFC's were emitted. And regrettably, I do not believe that global carbon dioxide emissions will stay below current rates nor do I believe that CFC's emissions will not continue.

The issues of global change are not like the issues that we focused upon 21 years ago when I served as faculty chair for the first Earth Day at UNH. Then we were primarily concerned about the pollution of the Merrimack River and other relatively local point-source issues. Today, the issues of global change are neither local nor point-source. They are persistent and long-lived. The questions that we need consider must address policies directed at decreasing the forcing terms (e.g., reduce fossil fuel carbon dioxide emissions), but we must equally confront the difficult scientific issues of how the Earth system will evolve as the suite of greenhouse gas increases, stratospheric ozone losses continue, new changes in the chemistry of the troposphere appear, continued destruction of tropical forests and wetlands, and increasing populations all continue collectively to occur. Not to mention, tomorrow's changes that will occur and that are not on this short, 1990-perspective list.

Climate change is important but it is not the only change that is important. The ozone losses in the stratosphere are important but they are not the only important change. Understanding these and other changes requires a suite of interlocking observing systems and scientific investigations. Some of the space-borne instruments will be targeted at a specific issue (generally for monitoring) like the Total Ozone Measuring Satellite; others will be focused on a key component of the Earth system such as the Tropical Rainfall Mission or the Upper Atmosphere Research Satellite (UARS), and others like the EOS–A series will focus on obtaining a more complete and consistent view of a major portion of the Earth system. Furthermore, a central requirement for the EOS mission is the development of scientifically credible long-term data sets. The fundamental importance of such long-term data sets is most easily appreciated when we consider the central role of the ice core CO_2 record with the Keeling direct atmospheric measurement.

As chairman of the EOS Payload Advisory Panel, I am personally familiar with the debate concerning which instruments should fly on EOS and when. The panel, which is composed of representatives of the 28 (attachment 1) Interdisciplinary Science Investigations (which represent a variety of disciplines and countries including Brazil, Canada, France, Japan, United Kingdom, as well as the United States), struggled with these issues. I would like to include for the record the three lengthy letters (attachments 2–4) that the panel wrote to the Associate Administrator for Space Science and Applications that addressed the issues of which instruments should fly, how they might fly, how to descope the payload, and the effects of descoping. The actions of NASA to date with respect to the EOS–A series instrument selection and implementation are completely consistent with the recommendations of the Payload Advisory Panel.

3. There appear to be three, at times interconnected, controversies surrounding EOS. The first is timeliness, the second is payload and platform size, and the third is budget.

a. All of us would like to accomplish almost everything quicker and faster. It is both a national strength and a weakness. The primary driver on the EOS schedule are the budget envelopes and associated rate at which major instruments, like MODIS–T and MODIS–N, can be built. It is not an issue of platform size. Fortunately, there will be a series of important Earth probes as well as greatly increased availability of existing data during the period between now and the flight of the first EOS–A platform. In this regard, the Tropical Rainfall Mission deserves special attention. It may be possible to add the CERES instrument and SAGE III to this payload. CERES in low inclination Earth orbit was planned for the Space Station but this capability was lost in the descoping of the station. The Payload Advisory Panel recommended early flight of SAGE III in a low inclination orbit, and in the discussion presented by Dr. Jim Hansen on a possible small climate satellite these two instruments were among the four recommended.

The so-called gap between now and the flight of EOS will not be a gap in important scientific activity; it will not be a gap in achieving new observations. The entire international scientific community needs an orderly progression to EOS and the long-term effort that it demands. The problems are not short-term problems for which there is a "quick-fix."

b. The payload size is a complex issue. I am not enchanted with things big; however, just because the EOS–A payload requires a large platform does not mean it is bad. Two cases in point: UARS is a multi-instrumented large platform and it is on schedule and on-budget; whereas, TOPEX is smaller with only a few highly focused instruments and is running late and overbudget. I might note that the A-series polar platform for EOS is on the historic trend line for Earth observing satellites in both mass and volume.

The subject of implementation has been debated extensively. The payload panel, using the top-most science issues in the U.S. Global Change Research Program as the guide for instrument selection, addressed the issue of payload and platform size in the April 25, 1990, letter to NASA (attachment 3). This information was shared with the ad hoc National Academy of Sciences Committee that reviewed the U.S. Global Change Program: 1991. This committee supported the large platform implementation for the A-payload. The Advisory Committee on the Future of the U.S. Space Program supported the Academy's findings.

The idea of breaking the A-payload into separate smaller spacecraft in order to insure a more resilient program is a red herring. To use an Atlas II (S-series) launch vehicle (ignoring for the moment that currently there are no planned launch facilities out of the Western Test Range for the Atlas II) to implement an A-series instrument complement would require three spacecraft to be flown in formation or nine launches over 10 years as opposed to just three for a Titan IV implementation (the current baseline). Assume each launch has a probability of .95 for success, then the probability that the three large platforms will be launched successfully (assuming independent events) is $(.95)^3=.86$. The probability that the nine Atlas launched payloads will all be successful is $(.95)^9=.63$.

Once on orbit the larger platform will only require one orbit adjustment every year to maintain the proper ground track. In the Atlas implementation two of the three smaller platforms must make an orbit adjustment every 2–3 days or several hundred times a year! The ability to develop credible long-term records will be compromised by the increased complexity that would be introduced by using multiple spacecraft in a formation mode. There are a number of such issues associated with smaller payloads, which is probably why the U.S. Air Force decided to move to the larger Titan IV and away from the Atlas II.

The Atlas launch or smaller payload implementations will not add resilience; rather I believe that it is being suggested to make it easier to cut essential items while appearing to support the program.

I think the implementation of the B-series instruments in the EOS Program is an open, difficult question.

c. EOS is expensive. So are a variety of things that the Federal Government does. EOS is not unrealistically expensive. The data system is essential and should not be compromised. The scientific investigations are appropriately scaled. The A-payload is already descoped. The issue of the implementation of B-series instruments remains open for debate. Clearly, the reasonable answer for the B-payload is somewhere between a complete implementation of all candidate instruments and none. The later case would be inconsistent to the problems facing the planet; the former may be inconsistent with the budget issues facing the country. In the end, it really is a mater of priorities—just how much is our planet worth?

ATTACHMENT 1

APRIL 20, 1990.

Dr. LENNARD A. FISK,
Associate Administrator for Space Science and Applications, Code E, NASA Headquarters, Washington, DC 20546

DEAR DR. FISK: In October 1989, the Investigator Working Group (IWG) of the Earth Observing System (EOS) formed a Payload Advisory Panel, composed of representatives from each of the Interdisciplinary Investigations. The purpose of the Panel is to provide advice to NASA on the composition of the EOS payload from the perspective of science.

The Payload Advisory Panel met on 23 and 24 January to continue deliberations, which were begun six weeks earlier at the first Panel meeting in New Hampshire. During the interval between the New Hampshire meeting and the meeting in late January, most of the other panels of the IWG met to consider issues that the Payload Panel raised in New Hampshire.

The findings of the Panel as expressed in this letter were presented to the full IWG in late March.

The issues that the EOS Payload Advisory Panel have been considering are of enormous importance to NASA, to the nation, and to the planet. Understandably, and perhaps fortunately, the conflicting demands that this consideration raises have no unique resolution or solution. Assuming realistic boundary conditions regarding resource availability (weight, power, data rate, cost, etc.) and accommodation considerations, there are a variety of feasible "solutions," each with strengths and weaknesses. This multiplicity is simply a reflection of the fact that the issues are highly complex and interwoven. The Panel, however, does not want to retreat to a position of giving "on the one hand on the other hand" advice.

A consensus has emerged from the Panel on a recommended core instrument payload for the A and B Observatories. The Panel has adopted a prioritization scheme for considering instrument selection. The Panel has defined a set of unresolved issues requiring additional study that it has charged to both the Project and other Panels of the IWG. The Panel will hold a meeting during the last week in August in order to provide your Office with subsequent considerations. In sum, this process of providing advice on the EOS payloads must be iterative; however, we can provide core advice now that is already well-considered.

The Panel adopted the Committee on Earth Sciences (CES) prioritization scheme for the U.S. Global Change Research Program. This prioritization scheme exists within a larger context of Earth System Science, as expressed in the report of the Earth System Science Committee of the NASA Advisory Council, which seeks to understand the evolution of the planet on all time scales; however, change on the decades to centuries time scale remains the central focus.

The Panel strongly supports the following instruments as providing the core observations for the U. S. Global Change Research Program:

From the NASA Polar Observatories (in alphabetical order): AIRS, ALT (see Study Issue III.B), AMSU (see Study Issue III.A.1), CERES-IN, EOSP, GLRS, AMSR/HIMSS/MIMR, HIRDLS, HIRIS, ITIR (Thermal and Stereo—see Study Issue III.A.2), LIS, MISR, MLS (see Study Issue III.A.3), MODIS-N, MODIS-T, MOPITT/TRACER, SAFIRE (see Study Issue III.A.3), SAGE III (see Study Issue III.C), SOLSTICE, STIKSCAT, SWIRLS (see Study Issue III.A.3), TES (see Study Issues III.A.3 and III.D).

In support of this package and from the NASA Polar Observatories: COMMUNICATION PACFAGE, GGI, WBDCS.

If resources permit and from the Polar Observatories: PARTICLES AND FIELDS INSTRUMENTS (see Study Issue III.E).

From European and Japanese Polar Observatories: The importance of resolving diurnal fluxes as well as providing other critical observations of parameters whose temporal variation is on a scale of hours (such as precipitation) argues for a close collaboration with the European and Japanese Polar Observatories. It is crucial that observations such as those taken with MODIS be extendable to the crossing times of the European and Japanese Observatories. In addition, the LAWS instrument, a U.S. contribution to the Japanese Polar Observatory, is central to the U.S. Global Change Research Program.

From NOAA: The operational instruments will continue to make a fundamental contribution to the U.S. Global Change Research Program, and this data must appear in a timely fashion in the EOS Data and Information System for the research community.

From Earth Probes: TRMM and perhaps A1T and/or SAGE III. Precipitation cannot be sufficiently well measured by a satellite in sun synchronous polar orbit, and this measurement is central to Global Change. Because of its low inclination orbit, TRMM will provide diurnal coverage that is not possible with the planned sun-synchronous orbits of the polar observatories; therefore, it is essential that TRMM be launched on an Earth Probe as soon as possible and that this capability to measure precipitation be maintained for much of the EOS Platform A five year timeframe.

The possibility of flying A1T or SAGE III on an Earth Probe is discussed in Sections III.B and III.C.

From a free-flyer: SAR. Many important properties of ecosystems are not well measured by radiometers and/or spectrometers because of cloud cover or simply because of the geometry of the vegetation. Similarly, the observation of sea ice properties important in air-sea-ice heat and moisture exchange—namely, thin ice and snow cover—is poorly served by visible, IR, passive microwave, or even single channel SAR's. These properties are best measured by an active, multi-parameter microwave instrument: the EOS SAR. This instrument can build upon SAR flights from the SIR systems through the ERS-1, JERS-1, and RADARSAT, thereby extending valuable

knowledge into the Polar Observatory era. We also note that SAR is an essential instrument for many of the volcanology studies. Because the SAR provides measurements needed to understand Global Change, it is important that it be flown as soon as possible after the EOS A-Observatory launch.

This suite of instruments is required to respond satisfactorily to the challenges of the U.S. Global Research Change Program.

The Panel believes that for maximum scientific benefits the payloads for the Polar Observatories should be organized around central themes in the U. 5. Global Change Research Program: changes in global biogeochemical and hydrological cycles and the couplings of these changes to the planet's physical-climate system. There are enormous synergistic benefits that result when instruments are focused on a central theme. We will mention some of these synergisms which have been found to be essential to obtaining the required accuracy of certain measurements. However, of equal importance may be the as yet undiscovered interactions between compatible instrument products.

The Panel recommends that the A-Observatory (and the associated free-flyers) have as a central focus the physical-climate system including the atmospheric structure and circulation, mass and thermal aspects of the cryosphere, the hydrological cycle, land- surface processes, and the dynamics of terrestrial and marine ecosystems, including their coupling to the physical-climate system and their influence upon the chemistry of the atmosphere, particularly the troposphere. As a consequence, measurements should focus upon observations that provide information about fluxes at the Earth's surface or the coupling between the troposphere and the stratosphere.

The B-Observatory should extend the observational foci into the stratosphere and should expand the set of measured chemical species in the troposphere as well as providing additional important Earth-surface information such as ice sheet topography and tectonic deformations.

Recognizing these basic themes for each Observatory provided guidance to the Panel as it sought to optimize the scientific return by proposing combinations of instruments that respond to the requirements and advantages of instrument synergisms and observational simultaneities and congruities. In seeking to optimize the payload grouping, two sets of issues emerged: recommendations that the Panel feels comfortable to make now and specific requests for additional studies to clarify issues that currently block potential recommendations.

The Panel focused primarily upon the EOS-A Observatory. Obviously, the instrument groupings by Observatory are coupled, and many considerations of the payload for the A-Observatory must confront the nature of the EOS-B payload, the instruments on the European and Japanese Polar Observatories, the NOAA operational instruments, and those free flyers that should be launched during the A-Observatory timeframe, all of which form an essential complement to the NASA Polar Observatories. In this context, the Panel assumes and supports that SeaWIFS, UARS, TOPEX, and a follow-on TOMS are going to fly. This is central. We did not discuss whether or not the B-Observatory should fly in the same orbit as the A-Observatory. Further, because of the importance of the diurnal cycle and precipitation, it is the sense of the Panel that additional observational capability will be needed in a lower inclination orbit. This capability should be compatible with some of the A-Observatory instruments.

The Panel kept these couplings in mind throughout the discussion. Issues of synergism, and the resulting necessity for observational congruence (observing the same place at the same time), observational simultaneity (observing almost the same site within 10's of seconds), and close sequential observations (observing almost the same site within 10's of minutes) were debated. This synergy comes in two principal forms:

(1) Instrument synergism is the use of observations from one instrument to improve those from another. For example, the use of AMSR/HIMSS/MIMR to correct the scatterometer measurements for atmospheric liquid and water vapor absorption.

(2) Science synergism is self-defining, and it is at the core of much of the research that will be made possible by EOS. Consequently, examples are numerous; for instance, the congruent and simultaneous measurements of temperature and water profiles (AIRS/AMSU), liquid water amount (AMSR/HIMSS/MIMR), cloud optical properties (MODIS), radiation budget quantities (CERES), and surface vector winds (STIKSCAT), allowing the diagnosis of cloud-water vapor-climate feedback processes over the ocean is but one of many examples of the importance of observational congruence and observational simultaneity in the investigation of important scientific issues.

In the following recommendations, the rationale is provided. It is particularly important to note the central role that instrument and science synergy and observational congruence and simultaneity and close sequential observations play in these recommendations. The A-Observatory emerges as a unit; the B-Observatory is composed of two somewhat decoupled units of atmospheric chemistry and solid Earth processes although there is some coupling such as the use of GLRS to measure cloud geometry. As mentioned, our recommendations regarding the B-Observatory are still incomplete and not yet comprehensive.

I. THE PAYLOAD ADVISORY PANEL RECOMMENDS FOR THE A-OBSERVATORY THE FOLLOWING INSTRUMENTS (in alphabetical order):

AIRS, ALT (see Study Issue III.B), AMSU (see Study Issue III.A.1), CERES-IN, COMM PACKAGE, EOSP, GGI, AMSR/HIMSS/MIMR, HIRDLS, HIRIS, ITIR (Thermal—see Study Issue III.A.2), LIS, MISR, MODIS-N, MODIS-T, MOPITT/TRACER, STIKSCAT, WBDCS.

This requires the following adjustments to the Violet payload (as presented by the EOS Project to the EOS Nonadvocacy Review Panel in October 1989) for the A-Observatory:

A. Move STIKSCAT from the B-Observatory to the A-Observatory.

STIKSCAT: STIKSCAT data play a vital role in many important EOS objectives, and the recommendation to move it to the A-Observatory is made with full awareness of the consequent demands in platform and financial resources. The rationale for moving STIKSCAT to EOS-A results both from instrument synergism (between STIKSCAT and AMSR/HIMSS/MIMR) and from science synergism (STIKSCAT provides the only all-weather measurement of surface wind velocity, which, when combined with measurements from AMSR/HIMSS/MIMR and other instruments, allows accurate calculation of important air-sea fluxes). In view both of the importance of our recommendation and the programmatic impact which it may have, we present the arguments in detail below.

Instrument synergism. The accuracy of STIKSCAT vector wind measurements can be improved and biases removed by using AMSR/HIMSS/MIMR integrated liquid and gaseous atmospheric water measurements to correct the STIKSCAT backscatter measurements. The correction is important. For example, synoptic-scale storms are extremely important in modulating the upward nutrient fluxes in the upper ocean and through the air-sea interface, and hence in regulating primary productivity. Unfortunately, the same synoptic-scale disturbances result in large atmospheric attenuation signals. Thus, accurate correction of scatterometer measurements by AMSR/HIMSS/MIMR will be required to eliminate (possibly substantial) biases in the winds and resulting nutrient/carbon flux calculated quantities. This correction is particularly important to studies of storms and connective cloud clusters.

The attenuation correction does not require observational congruence, since the attenuation layer is thin relative to the horizontal scale of the required correction (25 x 25 km resolution of the scatterometer); the required horizontal scales are large compared with the scales of individual cloud features; and the fact that the bulk of the attenuation takes place in the lower troposphere. Hence, the correction can be made although AMSR/HIMSS/MIMR and STIKSCAT do not image the same locations through precisely the same paths. What is required is that the radiometer and scatterometer measurements be obtained on a time scale that is short compared with changes in the atmospheric attenuation (cloud) field. Analysis based on consideration of scatterometer spatial resolution and atmospheric horizontal advection suggests that measurements obtained within the timeframe of observational simultaneity are required, and this can only be achieved by having the (forward looking) AMSR/HIMSS/MIMR and the (aft looking) STIKSCAT on the same platform.

Science synergism. The calculation of air-sea fluxes of moisture and heat requires data from both AMSR/HIMSS/MIMR and STIKSCAT, and the momentum flux requires accurate (i.e., attenuation corrected) STIKSCAT data. If corrected STIKSCAT data were available, (i.e. by flying a radiometer with STIKSCAT) the AMSR/HIMSS/MIMR and STIKSCAT instruments would not need to fly on the same platform, since each instrument individually measures the important scales of variability of its own geophysical field(s). Thus accurate fluxes could be calculated from close sequential observations during the time period that both instruments were in a tandem orbit. However, when both instruments were not in orbit (such as during the period between the launch of EOS-A and EOS-B) accurate fluxes could not be obtained; detailed analysis of the role of air-sea fluxes could not begin until both instrument were flying, and the total flux time series length would be restricted to the joint flight period. It is not possible to state with precision the "scientific impact" of a shortened and delayed time series. It is important to note, however, that El Nino-Southern Oscillation (ENSO) events (the strongest known climate signal on decadal time scales) occur only every 4-7 years; therefore, even a full 15 year time

series may lack statistical reliability. Our lack of understanding of air-sea influences on climate results in large part from our lack of an adequate historical record and the consequent inability to resolve and analyze multiple ENSO-type events.

Thus, the perspective of instrument synergism, the importance of the science, and the associated necessity for the development of a long-term record all argue for the inclusion of both the AMSR/HIMSS/MIMR and STIKSCAT instruments on EOS-A.

B. Move MOPITT/TRACER from the B-Observatory to the A-Observatory.

MOPITT/TRACER: It is an open and important question as to whether or not the oxidizing capacity of the troposphere is changing. Central to this are changing concentrations of CO and ozone. The linkages of CO and O to other atmospheric constituents are important; increases in CO emissions may be linked to the observed increases in methane concentrations, an important greenhouse gas. Likely emission sources such as biomass burning mapped by MODIS-HIRIS-ITIR (thermal) and complementary CO tropospheric measurements would be very valuable. Carbon monoxide in the troposphere can be measured from space, and it is appropriate to measure it from space. It cannot be sufficiently well-mapped by aircraft campaigns since it is too long-lived, however, trend estimates from ground-based networks are inadequate because it is too short-lived. Both TRACER and MOPITT can make this measurement of CO.

With regards to instrument synergism, MOPITT needs AIRS-AMSU data; whereas, TRACER is not heavily dependent upon AIRS-AMSU data, but CO retrievals from both would be enhanced by temperature data from the AIRS-AMSU system. Both instruments need cloud cover information and have internal capability for its determination, but detailed cloud cover information would help both instruments considerably. Given the scale of temporal variability for the cloud fields, this further argues for observational simultaneity with MODIS-N on the basis of field-of-view considerations.

From the perspective of an important, timely contribution to the U.S. Global Change Research program, we recommend flying either MOPITT or TRACER on the A-Observatory.

C. Add EOSP to the A-Observatory.

EOSP: Aerosols are one of the most important climate forcings that must be monitored to interpret observed climate variations, to understand the feedback processes of clouds, and to isolate the role of greenhouse gases. EOSP provides important information on cloud and aerosol vertical distributions and their properties (e. g. aerosol size distributions, phase of cloud particles). Although this instrument makes spectral intensity measurements similar to those of other instruments, it also makes unique polarization measurements which augment the amount of information obtained from spectral intensity measurements alone. Specifically, the polarization measurements alone allow a direct separation of stratospheric and tropospheric aerosols. Monitoring both types of aerosols, particularly tropospheric, is crucial for determining total climate forcing.

Although other instruments included in the Violet payload provide information on aerosols (e.g. MODIS-T and MISR), the Panel believes that this presents no unnecessary redundancy. For instance, MISR provides routine global monitoring of land surface multi-directional reflectance and hemispherical albedos as well as aerosol observations. In addition, because of its multi-directional capability, MISR's retrievals of aerosols over heterogeneous surfaces, such as most of the terrestrial biosphere, are uniquely valuable. Finally, since MISR and EOSP use different techniques (multi-angle imaging vs polarimetry), their aerosol measurements are likely to be complementary rather than redundant; the synergism between MISR and EOSP should be quite powerful.

In view of its importance to the U.S. Global Change Research Program, its complementarity to the basic instruments on the A-Observatory, and in view of its very modest demands for resources, the Panel recommends EOSP for the A-Observatory.

D. Move HIRDLS from the B-Observatory to the A-Observatory.

HIRDLS: The chemistry of the troposphere, the coupling between the troposphere and stratosphere, and changes in stratospheric composition are important aspects of the changing atmosphere. HIRDLS can globally monitor ozone, source gases from the troposphere, nitrogen radicals and reservoirs. The high vertical and horizontal resolution of the HIRDLS measurements can provide significant new information on the dynamics of the stratosphere and on troposphere-stratosphere exchanges.

HIRDLS measurements in the upper troposphere of long-lived, vertically well-mixed gases with tropospheric sources, such as methane and N_2O, provide tropospheric values for these gases down to the boundary layer. Measurements of ozone and water vapor in the upper troposphere allow the OH radical concentration to be estimated; HIRDLS provides valuable insight into the state of two of the main fac-

tors controlling the oxidizing capacity of the atmosphere. In addition, the total tropospheric ozone column can be usefully determined by subtracting the stratospheric ozone determined from HIRDLS from the total ozone column as determined from MODIS, AIRS, or TOMS measurements. This is already being done with SAGE II and TOMS (in sunrise/sunset regions where SAGE II can obtain a profile—see SAGE III discussion: Section III.C) with good results. It should be noted that this determination by HIRDLS and SAGE III of upper troposphere water and ozone concentrations is of critical importance; these are key unknowns for climate change.

As discussed in Section I.B, MOPITT/TRACER can provide information on CO, another key actor in determining the oxidation state of the lower atmosphere. Thus, HIRDLS has important synergism with the MOPITT/TRACER instruments. HIRDLS also serves to improve atmospheric temperature and water vapor soundings around the tropopause, through synergism with AIRS/AMSU. This improvement, thereby, provides temperature soundings from the surface to the mesopause. While we recognize that these measurements could perhaps be made in a close enough time-space frame by flying them on the B-Observatory, their importance to the pressing issues of Global Change suggest moving HIRDLS forward to the A-Observatory. If cost/platform constraints make this impossible, then consideration should be given to moving SAGE III forward instead.

II. THE PAYLOAD ADVISORY PANEL RECOMMENDS FOR THE B-OBSERVATORY THE FOLLOWING INSTRUMENTS (in alphabetical order):

COMM PACKAGE, GGI, GLRS, ITIR (Stereo—see Study Issue III.A.2), MLS (see Study Issue III.A.3), SAFIRE (see Study Issue III.A.3), SAGE III (see Study Issue III.C), SOLSTICE, SWIRLS (see Study Issue III.A.3), TES (see Study Issues III.A.3 and III.D).

We note that this recommendation may undersubscribe the physical resources of the B-Observatory; however, further recommendations will require subsequent investigations (e.g. Section III.E). This recommendation requires the following adjustments to the Violet payload (again see Attachment 3) for the B-Observatory:

A. Add SWIRLS to the B-Observatory.

SWIRLS: The dynamical information provided by SWIRLS for the stratosphere will significantly advance our understanding of the chemical transport processes in both the polar regions and in the tropics. SWIRLS represents a significant advance over the UARS-equivalent instrument, HRDI, in that both night and day winds can be measured throughout the whole stratosphere region. The Panel feels that this instrument is an integral part of the stratosphere chemistry package on the B-Observatory.

B. Add TES to the B-Observatory (see Study Issues III.A.3 and III.D).

TES: Changes in the biogeochemical cycles of the planet and, in particular, the changes in the chemistry of the troposphere are central to the U. S. Global Change Research Program. TES is not a candidate instrument for the A-Observatory. If it were, the Panel might likely recommend TES over MOPITT/TRACER since TES has greater capability. Adequately using this capability, however, requires further consideration, and the Panel recommends further investigation by the Project and by the Atmosphere and Biogeochemical Panels on the potential role of TES and its possible inclusion on the B-Observatory (see III.A.3 and III.D).

C. An assessment of the suitability of all of the Particle and Field instruments is recommended.

PARTICLES AND FIELDS: The Panel regrets that it has not yet been able to discuss the various instruments devoted to the measurement of the environment of the Sun-Earth system, and therefore it is unable at present to make substantive recommendations regarding the Particles and Fields instruments.Finally, the issues of synergism, both instrument and science, and the considerations relating to congruence, simultaneity, and close sequential observations are, clearly, at the center of the implementation of EOS as well as being the foundation for most of the scientific investigations. In the light of the latter, it is obvious that the issues are "open-ended;" however, their importance to the implementation suggests that our full consideration become part of the record and that we not restrict our discussion to just those issues associated with the—preceding specific recommendations. Consequently, we shall summarize the central points that emerged from our discussions in a subsequent letter, which might best be viewed as a technical appendix to this letter.

III. ISSUES REQUIRING FURTHER STUDY.

A. All instruments, particularly those that measure similar energy signals or similar geophysical parameters, must continue to be cross-evaluated for unnecessary redundancy.

EVALUATION GUIDELINES: The Panel does recognize that measurement of the same or related geophysical/biophysical parameters, using different approaches (e.g. using different spectral bands) with multiple instruments, can significantly improve

accuracy and reliability. In light of the requirement for long-term records, the increase in reliability is very important. Achieving a reasonable balance between minimizing overlap and maintaining the desired redundancy is essential if we are to ensure convergence toward a near-optimal, achievable, scientific payload. As the Panel went through the review, it identified three issues that merit further investigation by IWG Panels, by the Project, and by Headquarters.

A.1. The two sounders, AMSU A&B, and AMSR/HIMSS/MIMR need to be considered for unnecessary redundancy or cost-savings. This consideration should involve the Project; the relevant instrument PIs, and the IWG Panels (e.g. Atmosphere, Land Surface, etc.).

AMSU A&B can provide important measurements of water vapor profiles in cloud-covered areas. During the January meeting, we discussed the possibility that by extending the AMSR/HIMSS/MIMR sounding capability by adding a channel at 50 Gz these measurements could be provided, and thereby, it might be possible to eliminate the necessity for AMSU A and B.

Since January, the issue has been studied further. AMSU A and B are cross-track (49.5 degrees cross-track from nadir) scanning instruments with scan patterns that best match those of AIRS and MODIS, which require an elimination of the cloud effects on their infrared channels. AMSR/HIMSS/MIMR, however, is a conical scanning instrument at a 46 degree satellite zenith angle. Simulations have shown that AMSU at 46 degrees satellite zenith angle has about twice the error as at nadir. This occurs only near the end of a scan line for AMSU but it would occur all the time for AMSR/HIMSS/MIMR. The MODIS and AIRS teams have further stated that for best results they require observational congruence to account for the effects of clouds and precipitation and that the observational simultaneity that might be possible with an expanded AMSR/HIMSS/MIMR is insufficient.

Still,- the full range of AMSR/HIMSS/MIMR-AMSU issues, including the requirements of AIRS and MODIS, merit further explicit consideration by the Project and associated principal investigators.

A.2. The ITIR instrument posed particular difficulties for the Panel. The ITIR is, in effect, three spectrometers. One telescope has 3 channels in the visible and near infrared (ITIRVNIR); one has 6 in the short wavelength infrared (ITIR-SWIR); and one has 5 channels in the thermal infrared (ITIR-TIR).

Several issues arose regarding the ITIR instrument at the January meeting. In the following text, we review some of those issues and attach a report of the Solid Earth Panel (Attachment 4) that addresses some of these concerns.

From the Panel's perspective, and in consideration both of the CES prioritization scheme and the issue of instrument synergism, it seems that the thermal infrared portion of ITIR (ITIR-TIR) provides an important element of the A-Observatory capability. This aspect of ITIR would benefit from flight with MODIS and HIRIS.

The stereo imaging capability at 15m resolution for the 3 channels in the visible and near infrared (ITIR-VNIR) has the potential for developing a global topographic data base. This data base would be extremely valuable to a variety of scientific questions that relate directly to Global Change. It is unclear if the current design and assumed implementation of ITIR-VNIR has been approached with this global digital product in mind. Navigation and platform motion are serious problems for a stereo mission, and this may need further consideration.

There appears to be a valuable instrument synergism between the high resolution stereo mission component of ITIR-VNIR and the GLRS. It may not be necessary that both be on the same platform, although registration of control points and high resolution altimetric profiles from GLRS onto the stereo derived digital elevation models from ITIR-VNIR may improve the accuracy of the ITIR-VNIR product. This is considered in Attachment 4.

It would appear that the global mapping stereo mission of ITIRVNIR could benefit from a slower development schedule such as that for EOS-B. This would avoid an early freezing of the design to make an "A" launch. The importance of a digital topographic data set is so great that flight on the B-Observatory, where the GLRS will provide high accuracy control, should be considered.

The issues of topography and the ITIR-VNIR stereo capability should continue to be considered by the Solid Earth Panel and the ITIR team. The Hydrology Panel also should address these issues.

The remaining ITIR capabilities in the visible, near IR, and short wave near IR, need to be considered further. Attachment 4 provides a sound base for these considerations. These capabilities are partially redundant with HIRIS and MODIS-N, though the band passes and spatial resolution are different. As is noted in several portions of this letter (e.g. concluding remarks in Section III.A.3 below), redundancy is not bad and is, in fact, part of the insurance strategy for developing the necessary long-term data sets. This said, it is still the current sense of the Panel that flight

of the ITIR-SWIR should not cause any other sensor to be dropped from flight on either EOS-A or EOS-B. This position is consistent with the "back up" strategy that we present at the end of this letter (Section IV). Namely, the strategy should be developed in a manner that does not threaten any instrument in the essential scientific core payload.

We are recommending that the issues of ITIR scope and design be evaluated further. Most importantly, we request that you personally discuss with great diplomacy and care these matters with our Japanese colleagues. We also request that you discuss these issues with the Solid Earth Panel as well.

A.3. HIS, SAFIRE, SWIRLS, and TES should be considered together as an atmospheric chemistry package, and it is recommended that study be devoted to the possibility of reducing the scope of this set. For instance, it probably is not necessary, however, to measure the entire suite of middle atmosphere gases provided by the combination of these experiments in order to monitor changes or to investigate unique processes in the middle atmosphere. The Panel believes that there may be room for descoping the joint contribution of these four instruments, and therein, focusing on the most critical species needed to contribute insight into the most important scientific questions. The Atmosphere and Biogeochemical Panels should consider this further at a later date.

In summary, the Panel must note that while there is redundancy in constituent measurements between these instruments (as there is between other instruments); there is an open question as to the net gain achieved by descoping. Many measurements are made "for free" once a design is in place; furthermore, the importance of long-term measurements and the advantages for intercalibration, not to mention the expense of a "hot spare," all suggest caution in descoping simply to avoid relatively inexpensive redundancy.

B. The issue of flying a TOPEX-Class Altimeter (ALT) in the A-Observatory timeframe should be restudied.

ALT: Ocean altimetric measurements must continue to be made in the EOS A-Observatory timeframe. The Europeans may provide one set of measurements. Given the sampling scale and frequency achievable from a single radar altimeter of TOPEX class, observations which resolve mesoscale variability (the eddy structure) in the ocean require the flight of two altimeter instruments on separate platforms. Such eddy activity is a poorly understood component of the ocean heat budget which is crucial for understanding the physical climate system; moreover, the eddy structure is tied to the role of the ocean in the global carbon cycle. The Panel considered recommending that the ALT instrument be moved to the A-Observatory; however, an important issue requires further investigation.

What are the requirements for repeat-track and what platform control issues flow from these requirements? This is currently being investigated.

We recommend that the full suite of ocean altimetric issues be studied further by the Project and the Ocean Panel. Consideration should be given to a variety of approaches including flying the altimeter on an Earth Probe or another smaller satellite concurrently with the A-Observatory. We should note that ALT requires similar correction for water vapor absorption that STIKSCAT needs and hence there is instrument synergism between AMSR/HIMSS/MIMR and STIKSCAT. The actual hardware possibilities for altimetric measurements should be reviewed. In particular, the possibility of a solid state altimeter which could offer significant savings on mass should be explored.

C. The possibility of flying SAGE III on an Earth Probe prior to or in the A-Observatory timeframe should be reviewed.

SAGE III: SAGE III is a solar/lunar attenuation (occultation) instrument, and consequently, needs a sunset or sunrise (moonset or moonrise) to take data. Consequently, if it is in a polar orbit it will primarily make measurements in the two polar regions. Its strong attribute is that it has a unique capability for monitoring chemical species and physical parameters important to the ozone depletion problem in polar regions (the polar "ozone hole"): key chlorine and nitrogen species, ozone, aerosols, including polar stratospheric clouds, and temperature, all with very high vertical resolution in the altitude region where the ozone is an issue. The technique is also self-calibrating and, therefore, allows for long-term changes to be determined. Given that the A-Observatory will not be launched until FY 1998, there is a potential significant datagap between global ozone measurements provided by UARS and the possible observations by HIRDLS from the EOS A-Polar Observatory. These various lines of reason strongly suggest an early Earth Probe flight for SAGE III in a nonpolar orbit like its predecessor SAGE II (SAGE II is in a 56 degree orbit). The 56 degree inclination gives more global coverage, monitors close enough to the pole to measure for chlorine destruction, and low enough to capture an estimate for global ozone.

This should be followed by a later Observatory-B flight in order to maximize the critical polar coverage. Consideration should also be given to adding a low inclination orbit; wherein, SAGE III would also fly as an Attached Payload to Space Station Freedom.

The Panel recommends that the Project and the Atmosphere and Biogeochemical Panels consider the possibility of flying SAGE III on an Earth Probe prior to an EOS A-Observatory launch.

It should be mentioned that some members of the Panel felt that SAGE III should move to the A-Observatory rather than HIRDLS; however, the recommended configuration reflects a consensus.

Essential to this consensus is an early flight of SAGE III on an Earth Probe; moreover, as mentioned in the HIRDLS discussion (Section I.D) if cost/platform constraints make moving HIRDLS to the A-Observatory unlikely, then consideration should be given to moving SAGE III forward instead.D. The scope (pixel-size, swathwidth, and band-selection and sensitivity) of TES needs continued evaluation and definition.

TES: There is the sense that TES offers great potential for better understanding the chemistry of the troposphere and the role of biota and humans in changing chemical concentrations in the atmosphere. Continued consideration needs to be given to the most appropriate spatial/temporal coverage and necessary measurement accuracies for measuring the more rapidly varying chemical species in the troposphere. This consideration is underway, and we shall seek reports from the Atmosphere and Biogeochemical Panels.

E. The role and possibility of flight of instruments to measure the Earth environment in space (e.g. particles and fields instruments) merits further study.

PARTICLES AND FIELDS: The Panel supports an examination of the energy inputs to the Earth system as a result of its interaction with the interplanetary medium; however, such observations need to be accomplished without severely impacting the higher priority science goals of EOS. It must be noted that, in addition to the scientific insights that will be gained about the Earth and particularly the chemistry of the upper atmosphere, enhancing cooperation between Earth science and space physics is, in itself, important. There is also a long-standing tradition in the Office of Space Science and Applications of inter-divisional support in major scientific enterprises.

The actual probability of flight on EOS needs to Declassified by the Program and the Project in coordination with the Particles and Fields Panel (now called the Solar Terrestrial Panel).

IV. BACK-UP STRATEGY.

Underlying our discussions was the interplay between the issue of instrument failure and the importance of developing long-term data sets. This discussion is not complete, but in the spirit of setting forth as much counsel as possible, we share with you the current sense of the Panel: The Panel feels that no measurement is so critical that it requires a "hot spare" or a "backup launch on demand." The Panel recognizes that its recommendations regarding the EOS payload put additional pressure on the EOS budget and spending profile. It is our current view that the major sacrifices within the payload that a "hot spare" policy would impose are not justified by the value of the spare capability.

It should be recognized that the whole point of collecting a long-term data set, in addition to covering important longer term time scales, is to get "appropriate statistics," which in practice means getting enough data to overcome the effects of "gaps" in the record. Generally, in studying the Earth, one is not trying to detect a single event; therefore, gaps in a time series, while not helpful, can be overcome given enough data and given relatively infrequent and short gaps. Further, as we note at the end of Section III.A.3, the redundancy between instruments is, in effect, a "quasi-hot spare."

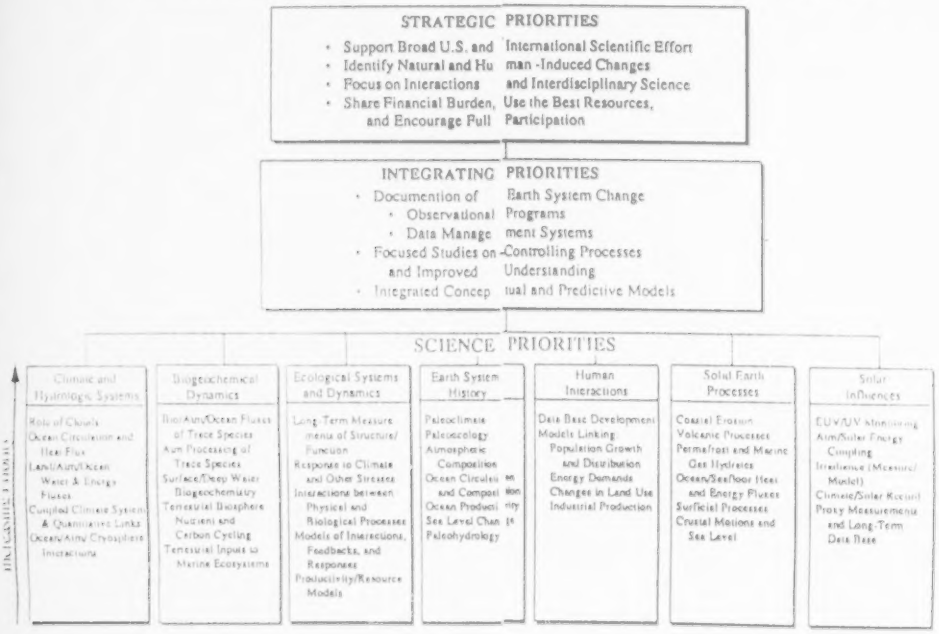
Finally, and in a similar vein with the issue of the "hot spare," the Panel concurs with the policy of fencing instrument contingency and that each instrument team should be forced to take its money and physical resource limits with great seriousness and to recognize that it will have to descope or even "fall off" the platform if it cannot live within those limits. The Panel believes that the scientific payload must push the physical resource limits of the platform and therefore all aspects of the payload and platform must be rigorously challenged to meet the budget limits. The Panel believes that it must actively participate throughout the period of payload selection and beyond in order to contribute to this challenging process. Specifically, once the EOS budget is clearer and the costs, masses, and power requirements for the instruments more refined, the Panel plans to reconvene in late August to provide additional advice to you with regards to the A-Observatory payload. We shall turn our attention to the B-Observatory in late fall of 1990.

We stand ready to be of further assistance to NASA.
Best regards,

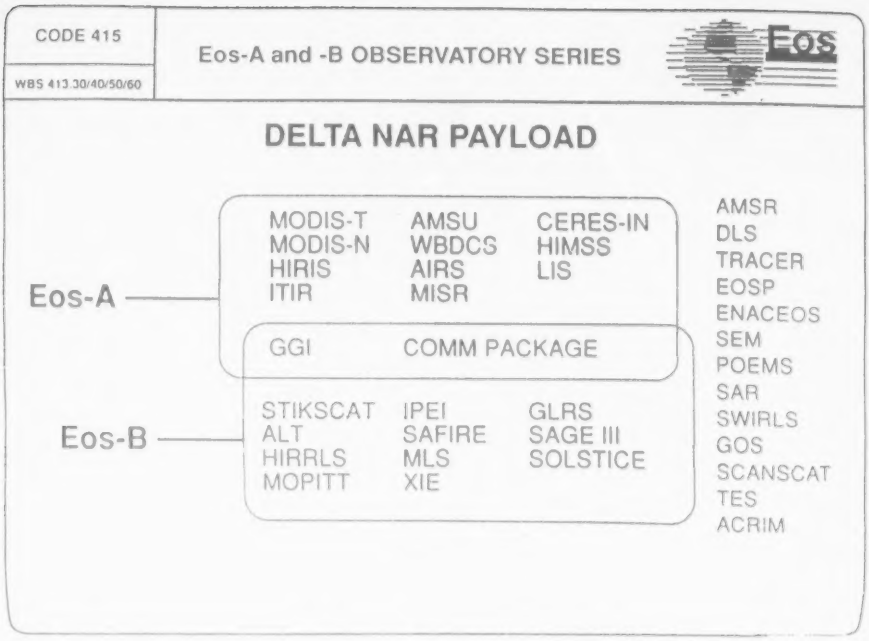
BERRIEN MOORE III.

Attachment 2.

U.S. Global Change Research Program Priority Framework


STRATEGIC PRIORITIES
• Support Broad U.S. and International Scientific Effort
• Identify Natural and Hu man -Induced Changes
• Focus on Interactions and Interdisciplinary Science
• Share Financial Burden, Use the Best Resources,
and Encourage Full Participation
INTEGRATING PRIORITIES
• Documention of Earth System Change
• Observational Programs
• Data Manage ment Systems
• Focused Studies on -Controlling Processes
and Improved Understanding
• Integrated Concep tual and Predictive Models
SCIENCE PRIORITIES
INCREASING TIMING
Climate and Hydrologic Systems
Role of Clouds
Ocean Circulation and Heat Flux
Land/Atm/Ocean Water & Energy Fluxes
Coupled Climate System & Quantitative Links
Ocean/Atm/ Cryosphere Interactions
Biogeochemical Dynamics
Bio/Atm/Ocean Fluxes of Trace Species
Atm Processing of Trace Species
Surface/Deep Water Biogeochemistry
Terrestrial Biosphere Nutrient and Carbon Cycling
Terrestrial Inputs to Marine Ecosystems
Ecological Systems and Dynamics
Long-Term Measure ments of Structure/ Function
Response to Climate and Other Stresses
Interactions between Physical and Biological Processes
Models of Interactions, Feedbacks, and Responses
Productivity/Resource Models
Earth System History
Paleoclimate
Paleoecology
Atmospheric Composition
Ocean Circulati on and Composi tion
Ocean Producti vity
Sea Level Chan ge
Paleohydrology
Human Interactions
Data Base Development
Models Linking Population Growth and Distribution Energy Demands Changes in Land Use Industrial Production
Solid Earth Processes
Coastal Erosion
Volcanic Processes
Permafrost and Marine Gas Hydrates
Ocean/Sea/floor Heat and Energy Fluxes
Surficial Processes
Crustal Motions and Sea Level
Solar Influences
EUV/UV Monitoring
Atm/Solar Energy Coupling
Irradiance (Measure/ Model)
Climate/Solar Record
Proxy Measurements and Long-Term Data Base

Attachment 3.



SOLID EARTH PANEL REPORT ON ITIR, SUBMITTED BY B.I. ISACKS, CHAIRMAN

The Solid Earth Panel met on March 20, 1990 and heard a presentation by the Japanese members of the ITIR team. Panel members raised and discussed with the ITIR team the issues posed by the January 1990 Payload Panel meeting. The following is a summary in terms of answers to two key questions posed by the Payload Panel.

QUESTION 1: How well can the stereo imaging capability of ITIR be developed to produce useful digital elevation data?

a. An effective and desirable base-to-height ratio of 0.6 is attainable with ITIR.

b. Errors estimated from consideration of base-to-height ratio, platform stability, and other factors are as follows: vertical: 25 m horizontal: 25 m effective horizontal grid spacing: 45 m

c. The ITIR topographic resolution would produce useful slope correction data for the interpretation of MODIS imagery (if it were obtained at the same time) and ITIR temperature data derived from thermal emission channels. The resolution is not sufficient for slope correction of HIRIS imagery.

d. There is synergism of ITIR and GIRS with respect to (1) GIRS obtaining the location of control points by placing retro-reflectors in the scenes imaged by ITIR, and (2) use of GLRS laser altimeter topographic sections to obtain a "controlled section" within the ITIR stereo scene. This synergism is not critical, however, because (1) control points can be obtained in other ways, including the use of standard GPS systems (the control points do not need the accuracy of GLRS), while (2) the altimeter spot of 70 m presents problems and the section does not provide control along the sides of the scene.

e. ITIR requires AIRS to make atmospheric corrections across all three spectral components to obtain temperatures and compositions.

f. The along-track stereo viewing of ITIR offers definite advantages over side-viewing systems such as SPOT in terms of achieving coverage of areas that tend to be cloudy, and could significantly increase the coverage of land areas not obtainable with SPOT. (Topography at roughly the same resolution as ITIR may also be available from JERS-1?)

g. In general, digital topography with ITIR resolution obtained over large continental areas would provide extremely valuable data for the study of land surface

processes, since topography is a primary control on the interactions of the land surface and the atmosphere. The digital topography of large areas of the earth's land surface are presently available only at very crude resolutions, with no plan to fill this gap yet developed much less in operation. ITIR could make a significant contribution to this need.

QUESTION 2: In view of certain HIRIS-ITIR redundancy, why not place the TIR component of ITIR on the A platform and the stereo VNIR component on the B platform?

a. The redundancy is primarily in the ITIR SWIR channels, where in principle those ITIR channels might be synthesized from HIRIS. This would, however, present problems of co-registration amongst different instruments.

b. The ITIR SWIR swath width more than twice as large as the equivalent HIRIS (60 versus 24 km). This is a critical difference for the volcanology project, where volcanic plumes can often be larger than 24 km and in unpredictable positions relative to the swath center line. ITIR would provide a more complete view of the plume, while HIRIS would see only part of it on a given pass.

c. The short wave infra-red (SWIR) and thermal infra-red (TIR) channels of ITIR provide important "spectral continuity" by being in the same package. This is required by the volcanological project to determine the temperatures of both hot (T = 500-1000 degrees C by SWIR) and cool (T = 200 degrees C by TIR) volcanic extrusions. The high resolution stereo visible and near infra-red (VNIR) channels are required to see the three dimensional character of the extrusions and provide data for slope corrections in a rapidly changing situation, and thus requires all three components viewing the transient phenomena at the same time. The resolutions of MODIS or MISR is not adequate for this purpose.

d. The ITIR instrument is carefully designed to be a very efficient tool for the mapping of geological structure and the mineralogical constituents of rocks and soils, but it works this way only with all three components together. Each component is sensitive to particular minerals, VNIR for iron oxides, SWIR for clays and carbonates, and TIR for silicates and carbonates. The stereo provides critical information both about structure and slope corrections. Separating the components into different packages and platforms destroys the essential synergism and purpose of the instrument design.

General: Important solid earth science objectives in EOS study of global change would be served by STIR, including monitoring of volcanoes, study of land surface processes in general, and mapping of paleoclimate. The STIR team also presented material on the role of STIR in studies of the hydrological regime and clouds, but this material should be considered by the appropriate SWG panels.

ATTACHMENT 3

APRIL 25, 1990

Dr. LENNARD A. FISK,
Associate Administrator for Space Science and Applications, NASA Headquarters, Code E, Washington, DC 20546

DEAR DR. FISK: In our letter of 20 April 1990 (Attachment 1), which contains the Payload Advisory Panel's initial payload recommendations, we promised to summarize the central points regarding instrument and science synergism and the associated issues of observational congruence (observing the same place at the same time), observational simultaneity (observing almost the same place within tens of seconds to minutes), and close sequential observations (observing almost the same place within 10's of minutes). This letter is- that summary.

In our 20 April letter, we presented our recommendations in what might be termed at "top-down" presentation in that we used the October 1989 NAR Violet Payload as a straw payload and presented detailed rationale for adjustments in that payload. This type of presentation does partially reflect the Panel's discussion but only partially. The Panel also discussed implementation in a more "bottom-up" context; wherein, each of the instruments was judged against their contribution to the Science Priorities (Attachment 2) in the Committee on Earth Sciences (CES) plan for the U.S. Global Change Research Program. Within this "bottom-up" debate, we also considered carefully which instruments should fly together and why.

Since instrument complements also bear upon the issue of whether to implement EOS by a large platform and a Titan IV launch, perhaps it would be helpful if we focused, in part, on the impact of our synergism discussion on issues of platform size and launch vehicle.

The issue of instrument complement is complex, and it is useful to consider order implications of the CES Science Priorities. For example, what instruments must be

flown if one were to focus simply' upon the highest CES priority item: Climate and Hydrological Systems: The role of clouds.

Eight instruments are essential: AIRS, AMSU A&B, CERES, EOSP, HIMSS, MISR, and MODIS-N.

There are several additional instruments that would be very valuable (GLRS, HIRIS, LIS etc), but for discussion we shall focus only upon essential instruments.

The first question is why are these eight instruments essential. The second question is what are the observational requirements, congruence, simultaneous, or close sequential observations, between these instruments. The third question is what is the impact of these requirements on the issue of launch vehicle.

A. Climate and Hydrological Systems: The Role of Clouds.

Clouds are a strong modulator of the shortwave and longwave components of the Earth's radiation budget (Ramanathan et al, SCIENCE 243, 1989). It is also recognized that a knowledge of cloud properties and their variation in space and time is crucial to studies of global climate change (e.g., trace gas greenhouse effects), as General Circulation Model (GCM) simulations indicate climate induced changes in cloud amount and vertical structure, with a corresponding cloud feedback working to enhance global warming. Recent GCM simulations include corresponding changes in liquid water content and cloud optical thickness, and suggest that changes in cloud optical properties may result in a negative feedback comparable in size to the positive feedback associated with changes in cloud cover. None of the GCM simulations to date include corresponding changes in cloud microphysical properties (e.g., particle size), which could easily modify conclusions thus far obtained.

In order to advance our understanding of clouds in the present Earth-atmosphere system, as well as to understand the role of clouds in climate studies arising from changes in cloud amount and optical properties associated with changes in climate forcing, it is absolutely essential to obtain simultaneous observations of the distribution of cloud optical, geometrical and microphysical properties from space-based observing systems. These observations should include the simultaneous determination of cloud optical thickness, cloud effective particle radius, liquid water path, cloud top pressure (or altitude), cloud top temperature, cloud emissivity, and cloud water thermodynamic phase (ice vs. water, snow vs. cloud). Such observations would be invaluable for determining not only the marginal probability density functions of these individual properties, but would also permit the determination of the joint probability density functions in a wide variety of climatological regimes. Furthermore, the near simultaneous determination of aerosol properties would permit the quantification of the extent to which clouds are directly correlated with aerosol.

In most cases, because of the high temporal variability of many of these parameters, the average of the computed property cannot be determined as a function of the averages of the measured parameters. Rather, the average values of the computed property should be determined from the calculated "instantaneous" values of the property itself.

The recent trend in the parameterization of the shortwave radiative properties of clouds in GCM models is to parameterize the reflection, transmission and absorption properties of clouds in terms of cloud liquid water path (or, alternatively, optical thickness) and effective particle radius. Similarly, the longwave properties of clouds are largely governed by the cloud top altitude, cloud emissivity and cloud top temperature. Thus the simultaneous determination of these cloud properties will permit advances in our understanding of the global climate system.

1. Instrument implications and rationale.

Clouds are among the high-frequency variables in the atmosphere. It is well-established that the cloud-atmosphere radiation interactions and the fluxes of heat and energy at the surface are known to exhibit a high degree of temporal and spatial variability. This variability must be taken into account in the observational mode of EOS if accurate computations of their properties are to be achieved.

We shall consider the simplest possible initial configuration: AIRS/AMSU A&B to provide atmospheric temperature profiles with 1 degree C accuracy and 1 km vertical resolution; CERES-IN to determine broadband shortwave and longwave top-of-atmosphere radiances; HIMSS to establish oceanic cloud water and water vapor content; MODIS-N to provide spectral information needed for determining the basic physical cloud properties and height (from infrared observations); EOSP (from its polarization data and using spectral information from MODIS-N) to determine aerosol composition; and MISR (through its multi-angle capability), to provide the bulk radiative properties of aerosols in the shortwave spectral region.

Because aerosols are spatially and temporally highly variable, and because their scattering properties are sensitive to the solar zenith angle, MODIS-N, EOSP, and MISR must, at least, have observation simultaneity if not congruence. Likewise, in order to separate aerosol and cloud influences on the observed radiances requires

flying CERES-IN and MODIS-N with EOSP and MISR. In addition, in order to convert the narrow spectral albedos of clouds determined by MISR to high spatial resolution broadband albedos necessitates simultaneous superposition of MISR on CERESIN fields-of-view.

A similar need for simultaneity between CERES-IN and MODIS-N exists and is perhaps best appreciated by a simple example. Typically, mid-level clouds move about 20-40 m/s. In order to correct the retrieved atmospheric and cloud properties for each 25 km CERES pixel, it is necessary to employ the fluxes calculated from MODIS-derived clouds and the associated broadband fluxes. To assure 80% pixel coherence of area means, the two instruments can not be out-of-simultaneity by more than three minutes.

In addition, the radiation determination by CERES-IN depend upon measurements of cloud properties by MODIS-N. These two data streams are to be combined into a single satellite swath of identified clouds and radiation. Overall consistency between cloud properties, humidity, temperature, and the high absolute accuracy radiance measurements from CERES is essential. MODIS-N HIMSS, AIRS/AMSU A&B, and CERES must be making essentially simultaneous measurements. Even allowing for differences in pixel size, CERES and MODIS not be out-of-simultaneity by more than three minutes; HIMSS and AIRS-AMSU have larger pixels; therefore, a 10 minute gap could be tolerated.

Another aspect in the role of clouds is their effect upon surface radiation fluxes. The main difficulty in deriving the global surface radiation fluxes is in estimating cloud properties. Global computation of surface fluxes is time consuming even when a horizontal grid of 50 x 50 km is used, which is equivalent to the spatial resolution of AIRS/AMSU A&B. However, the accuracy of the shortwave algorithm could be greatly improved if the cloudiness parameters were available simultaneously on a subgrid scale as obtained by MODIS. This would allow the cloud bi-directional reflectance correction functions to be properly included in the 50 x 50 km data of AIRS/AMSU A&B. A related issue is the cloud albedo determination. AIRS will provide the needed measurements for the 0.4 to 1.6 micrometers range. However, calibration of visible channels is a difficult task, and requires cross-calibration with CERES.

Another important issue is that of the surface visible albedo for which both higher spatial resolution measurements from MODIS and broadband visible measurements from AIRS are needed to improve the estimations. The Multi-Angle Imaging Spectro-Radiometer (MISR), which will provide aerosol optical depth and other properties, is another crucial instrument for computing the surface shortwave flux in clear conditions.

In the case of the longwave surface radiation flux, the high spatial resolution of cloudiness becomes less critical, in so far as it is the same 50 x 50 km resolution of the sounder. To derive the upward and downward spectral longwave fluxes we need to know the cloud infrared spectral properties, the surface infrared emissivity, the atmospheric temperature and humidity profile, and the surface temperature.

If we consider the issue of latent heat, then further arguments would emerge for flying subsets of these eight instruments together. What is evident is that consideration of just the Global Change scientific issues associated directly with the role of clouds requires the co-location of the following instruments:

AIRS, AMSU A&B, CERES-IN, EOSP, HIMSS, MISR, and MODIS-N.

2. Implication for implementation.

If the payload were only these eight instruments, and if we adopt the current payload to platform ratio of 30%, then this payload would exceed an ATLAS IIAS lift capability by 160 kg. If we reduced the margin and assumed a larger payload to platform ratio of 35%, then an ATLAS IIAS would be capable.

B. Biogeochemical Dynamics: Biosphere-Atmosphere-Ocean Trace Gas Fluxes.

This consideration, thus far, has essentially ignored the biosphere and any consideration of Biogeochemical Dynamics, which is the second priority area in Committee of Earth Sciences: U. S. Global Change Research Program. Again as a zeroth-order exercise, it is useful to consider just the highest priority component within the theme of Biogeochemical Dynamics: The biosphere- atmosphere and ocean-atmosphere trace gas fluxes. In order to simplify this further, we shall focus upon the exchange of carbon dioxide.

Six instruments are essential: ALT, HIRIS, MISR, MODIS-N, MODIST, and STIKSCAT.

Rather than present a parallel discussion on the importance of the biogeochemical fluxes between the land and atmosphere and the ocean and the atmosphere; and therein the rationale again on the importance of each instrument for ocean carbon studies, we turn directly to the issues of synergism and simultaneity.

1. Instrument synergism and simultaneity.

We first discuss MODIS-N and MODIS-T. The necessity of flying these instruments for global carbon studies does not require added justification; however, what is perhaps not so well understood is why two instruments are required and what are the simultaneity issues between MODIS-N, which is basically a land-focused instrument, and MODIS-T, which is measuring ocean color and hence marine biological activity.

The ocean is a very dark target with respect to the land, and to observe phytoplankton with ocean color techniques requires high sensitivity in order to separate the light leaving the ocean (which contains the signal of interest) from the much larger amount of light that reflects from the surface and from within the atmosphere. This is especially true in the near-IR, where precise observations of radiance from aerosols are needed so that the effect of aerosols can be subtracted from the visible channels, hence MISR simultaneity is required. In addition, ocean color observations require that the sensor tilt its swath away from direct solar surface reflection, otherwise sun glitter renders nadir observations useless for about one third of the orbit (within the tropics, which accounts for more than half of the global marine photosynthesis). Hence two instruments, MODIS-N and MODIS-T, are required.

For terrestrial applications, studies of the surface albedo and even for optimal use of the broad swath and spectral coverage of MODIS-N for vegetation studies, require evaluation of the effects of the spectral bi-directional reflectance distribution function (BRDF) in derivation of various geophysical properties including vegetation indexes and snow and ice cover. The BRDF describes quantitatively the effects of sun-target-sensor geometry, and can be appreciated by noting that shades and hues of many surfaces change depending whether one is looking toward the sun or away from it.

MODIS-T will be the principal instrument for making the BRDF determinations within plus or minus 50 degrees along track at nadir, and at greater angles at swath edges. However, accomplishing terrestrial BRDF (or even routine land observation at nadir scanning) presents at first glance, a conflict with the needs for glint avoidance for ocean color observations. Ocean sun-glint avoidance can be considered a special case of BRDF study, where one wants to avoid observing the full BRDF, especially that portion looking toward the sun's reflection. This is especially true within one swath width (1500 km inland and seaward) along the coast.

If the three complementary sensors MODIS-N, MODIS-T and MISR fly together, then this conflict can be resolved. MODIS-T viewing operations can give priority tilt coverage to oceans and major lakes, and it can perform dedicated terrestrial BRDF studies with 32 channels for inland regions with only minor impact to routine ocean observation. MODIS-N can collect global coverage with all spectral bands, at nadir only, but continuously, day in and day out, with finer spatial resolution than MODIS-T. MISR can collect BRDF observations with four spectral channels continuously over the globe, but with narrower swath and resulting less frequent regional coverage which is in keeping with the slower time rate of change for terrestrial ecosystems compared with their aquatic counterparts. In the latitudes and swath areas which are contaminated by sun-glitter, the ocean channels on MODISH will be used primarily to recover data in a small (5 degree) gap which results from the required tilt operation by MODIS-T.

There is another, highly exploratory synergism between MODIS-N and MODIS-T; wherein, MODIS-N will also be used to make new types of ocean observations which is impossible to acquire by MODIS-T while making ocean color measurements in the glitter-avoidance tilting-mode required for marine phytoplankton observations by MODIS-T. Specifically, simultaneous sun glitter observations by MODIS-N will be useful in providing estimates of wind speed, since the wind-induced capillary waves produce the geometry reflecting direct sun light to the platform similarly to, but with better theoretical understanding than, active microwave scatterometry. Patterns within the glint result from surface active compounds which dampen the capillary wave structure, and are greatly modified by fine and mesoscale circulation. These compounds arise both naturally from fish, krill, and phytoplankton blooms, and artificially as from oil spills. In addition, the presence of slicks has significant effects on gas and moisture fluxes through the air-sea interface (CO_2, O_2 and DMS) and their affect must be included in models of air-sea interaction. Such studies have not been possible in the past because CZCS tilted to avoid glint, and AVHRR lacked both sensitivity and spectral resolution. However, astronaut photographs from STS-6 have provided stimulating qualitative encouragement.

Exact congruency for MODIS-N and MODIS-T is impossible since they will view different angles along track. Necessary optical atmospheric correction channels are contained on each to avoid the need for congruency between the two. However, there is are clear needs for simultaneity as distinct from closely sequential: for correction

of ozone absorbance of MODIS-T by MODIS-N; subpixel cloud estimation on MODIS-T using MODIS-N 250 micrometer channels; correspondence of sea-surface temperature and ocean color for ocean front and eddy studies; relating terrestrial BRDF observations made with MODIS-T to routine vegetation observations of MODIS-N. HIRIS provides the essential subpixel detail needed to well-measure the anthropogenic changes that are occurring in the biosphere. The challenge is to relate the high resolution HIRIS information to the larger MODIS-N pixel. This problem becomes almost impossible if one introduces atmospheric differences. Sequential observations will be contaminated by varying wind fields affecting leaf structure, wind stress, and cloud motions. HIRIS, MISR, MODIS-N, and MODIS-T form a unit for measuring terrestrial and marine biological activity, and hence form the basis for estimating CO_2 exchange provided simultaneity is preserved.

As discussed in Section A, simultaneity of the MODIS sensors with AIRS/AMSU A&B is required since they will form couples in surface and cloud emissivity studies, and derive ozone for correction of MODIS and HIRIS visible channels. MODIS-N and CERES will form a couple in relating various cloud optical properties with earth radiation budget observations; closely sequential observations by MODIS-N and CERES would be aliased by cloud motions and changes in cloud position.

There is another important point in instrument synergy relates to the need for monitoring the stability of the optical instruments. The approach is to perform the best possible calibration pre and post launch to ensure high stability on the scan time period, to use on-board diffusers and solar integrating spheres for longer time periods, and since plates and integrating spheres degrade with time to use the moon as a standard of stability for the longest periods. In this approach, MODIS-T will have sufficient tilt to view the moon at full moon with full optics and thereby MODIS-T will serve as a long-term standard for the other radiometers visible sensors, CERES, MODIS-N, HIRIS, and MISR. Ideally, these four sensors would have observational congruency with MODIS-T, but simultaneity (within seconds) should suffice with enough measurements to get a good average and rigorous accounting for any biases.

2. Implication for implementation.

Thus, from the perspective of carbon cycle alone MODIS-T, MODIS-N, and HIRIS should fly together. Ideally, ALT and STIKSCAT would fly with MODIS-T; however, from the perspective of these instruments alone and the needed measurements, close sequential observations are perhaps sufficient. However, as discussed in the letter of 20 April, both STIKSCAT and ALT require near simultaneity with HIMSS (within minutes), and there were other reasons for flying ALT and STIKSCAT on the A-Observatory or in the A-Observatory timeframe. Finally, as discussed above, there is a variety of synergisms between the optical instruments (CERES, HIRIS, MISR, MODIS-N, MODIS-T) and the atmosphere sounding instruments (AIRS, AMSU A&B, and HIMSS).

Consequently, the observational and simultaneity requirements associated with just these two themes (Climate and Hydrological Systems: The Role of Clouds and Biogeochemical Dynamics: Biosphere-Atmosphere-Ocean Trace Gas Fluxes) require the following instruments be flown together:

AIRS, AMSU A&B, CERES-IN, EOSP, HIMSS, HIRIS, MISR, MODIS-N, and MODIS-T.

Assuming a payload to platform ratio of 30%, this payload would exceed the ATLAS IIAs capability by 3500 ffg; increasing the ratio to 35% still leaves 2,400 ffg excess. The problem is not resolved by removing the heaviest instrument (HIRIS) and assuming a 35% payload to platform ratio. The resulting payload would still be 220 kg. too heavy.

This payload: AIRS, AMSU A&B, CERES-IN, EOSP, HIMSS, HIRIS, MISR, MODIS-N, and MODIS-T forms the core of the NAR-Violet package. It also establishes the requirement for a Titan IV launch, which thereby sets some of the resource conditions for the platform. Consequently, part of the Panel's role became one of "optimizing" the payload within these constraints using the above payload as a core. This was the focus of the 20 April letter; in addition, as we noted in that letter, we have not yet given sufficient consideration to the B-Observatory series overall, and in particular, we have not yet properly considered the Particle and Fields instruments. We shall be turning our attention to the BSeries in the fall.

I hope these additional considerations are useful to you and the EOS Program.

Best regards,

BERRIEN MOORE III.

ATTACHMENT 4

Dr. LENNARD A. FISK,
Associate Administrator for Space Science and Applications, Code S, NASA Headquarters, Washington, DC 20546

DEAR DR. FISK: On 28-30 August 1990 the Payload Advisory Panel of the EOS Investigator Working Group met to consider further the recommendations that it made to you on 20 April 1990 (Attachment 1). The result of these considerations is a series of recommendations, focused primarily on the EOS-A platform series. We will begin to consider the B-platform series this November at the EOS IWG meeting at NASA Langley.

The Panel recommends that the A-platform series have as its combined focus the climate and hydrologic systems and ecosystem dynamics, including the structure and circulation of the ocean and atmosphere, the hydrologic cycle, land-surface processes, and the dynamics of terrestrial and marine ecosystems, including their coupling to the physical-climate system and their influence on the chemistry of the atmosphere, particularly the troposphere. As a consequence, measurements should focus on observations that provide information about fluxes at the Earth's surface or the coupling between the troposphere and stratosphere.

The Panel recommends for flight on the A-platform the following instruments (in alphabetical order): AIRS/AMSU, CERES, EOSP, HIRDLS, HIRIS, ITIR, LIZ, MIMR (or HIMSS), MISR, MODIS-N and MODIS-T, MOPITT or TRACER, STIKSCAT, and UBDCS.

This suite of instruments requires the following adjustment to the "Violet" payload, as presented by the EOS Project to the EOS Non-Advocacy Review Panel in October 1989 (see Attachment 1). Four instruments should be brought forward onto EOS-A or added to EOS-A: MOPITT/TRACER, STIKSCAT, HIRDLS, and EOSP. These four instruments are critical to studies of atmospheric chemistry, ocean/atmospheric dynamics, and the Earth's radiative balance. One instrument, GGI, should either be dropped from the EOS-A series as an economy measure or incorporated into the platform positioning system.

Because of issues related to resource availability on EOS-A, the Panel suggests two additional ways to reduce costs: 1) slip the launch of EOS-A by up to a year and build only two copies of HIRIS for flight on EOS-A and EOS-C or 2) do not slip the launch and build only two copies of HIRIS for flight on EOS-C and EOSE.

The highest-priority instrument to move forward is MOPITT or TRACER, because either instrument would provide measurements of CO and CH4 in the troposphere, information that is important for understanding atmospheric chemistry and its interaction with the biosphere.

STIKSCAT and HIRDLS are second in priority. Both provide important measurements and provide continuity with missions to be flown in the pre-EOS period. They address different disciplines, however, so the Payload Panel finds it difficult to choose between them. Those who study ocean circulation, air-sea interaction, atmospheric hydrologic processes and trace gas and energy fluxes clearly need the information on vector wind fields that STIKSCAT would provide. Moreover, STIKSCAT enables better synergism with the other imaging instruments on the A-platform, as ocean dynamics and cloud fields will be examined simultaneously. If launched on EOS-A, STIKSCAT would extend the data sets from NSCAT (on the Japanese satellite ADEOS) through the 1990s.

The stratospheric chemists clearly need information on global ozone and temperatures in the stratosphere and cloud-free regions of the upper troposphere that HIRDLS or SAGE III can provide. If launched on EOS-A, either of these instruments would shorten the gap in data sets provided by the OARS mission until about 1995, however, the panel recommends HIRDLS be moved forward. High- accuracy, high-resolution temperature sounding capability from the troposphere through the stratosphere is also a critical and immediate requirement for EOS. The Payload Panel endorses the temperature sensor complement provided by AIRS/AMSU and HIRDLS.

EOSP and SAGE III can provide independent measurements of aerosol properties in a low-cost instrument that enhances the information obtainable from MISR and MODIS. EOSP allows separation of stratospheric and tropospheric aerosols necessary to monitor their separate and different effects on climate by the combination of AIRS/AMSU and HIRDLS. EOSP is recommended for flight on EOS-A.

To avoid a break in the SAGE II data set, the SAGE III instrument is needed in the EOS-A time-frame. This, however, raises the question of geographical sampling for an occultation experiment and the preferred orbit to give the sampling necessary to address different science issues which are discussed in the recommenda-

tions concerning SAGE III. SAGE III on EOS-A would provide information about aerosol profiles, but only in the polar regions.

The Altimeter should fly on the B-platform or on a free flyer.

Selection of the Fields and Particles instruments should not compromise our recommended payload, which meets the primary science objectives of the EOS mission.

RECOMMENDATIONS CONCERNING TRACER AND MOPITT

The measurements made by TRACER and MOPITT are central to the Global Change problem, addressing global air pollution, biomass burning and changes in the tropospheric oxidizing capacity. In addition, both instruments measure methane, but only TRACER has sufficient accuracy to diagnose the regional sources. We do not see definitive differences between the two instruments in performance or data products for CO. MOPITT has the wider swath and therefore may provide better global coverage; however, TRACER has more heritage, does its own cloud screening, has a broader science team, and, as noted above, apparently makes better methane measurements that will be extremely valuable. Despite this, budget considerations and the importance of the CO measurement versus no CO measurement lead us to favor MOPITT.

We recommend that the EOS Program and your office give explicit, careful consideration to the full range of scientific and financial issues underlying the choice between MOPITT and TRACER. Such consideration may require a delay in the final selection; however, given the minimal schedule risks associated with these particular instruments coupled with their importance to the EOS mission, this possible delay in selection is acceptable.

If MOPITT is selected, we suggest that either members of the TRACER science team be included in the CO investigation, and/or that an Interdisciplinary Team be established to address the many questions about tropospheric chemistry that are important to the EOS mission.

We recommend that MOPITT or TRACER be included on the A-platform. The interdependence of MOPITT/TRACER with the EOS-B instruments is not as strong as with those on EOS-A; their synergism with MODIS-N will facilitate the study of biomass burning, an important science issue in global change.

We also recommend that a two-instrument buy be considered for MOPITT/TRACER, because if TES on EOS-B is successful, MOPITT or TRACER would be superceded.

RECOMMENDATIONS CONCERNING STIKSCAT

It is absolutely essential that all-weather surface vector winds be collected over the ocean in the EOS-A time frame. These data will allow critical studies in the area of atmospheric hydrologic processes over the ocean, air/sea energy and trace gas fluxes, ocean circulation, and ocean primary production. These studies, in turn, will further our understanding of the role of the coupled ocean/atmosphere system in regulating the global heat engine and the role of the ocean in carbon uptake and burial in the deep ocean. Scatterometer measurements are the only way to collect vector winds and will play a critical science synergism role. Lastly, the collection of scatterometer measurements in the EOS-A time frame will continue the time series of vector winds that will begin in 1995 by NSCAT onboard ADEOS.

There are two ways to obtain vector winds in the EOS-A era. First, STIKSCAT could be moved forward to the EOS-A platform. This would allow the co-location of STIKSCAT with MODIS, AIRS/AMSU, CERES and MIMR, which, in turn, would support investigations of instantaneous, high-resolution images of surface wind vectors and convergence with physical properties of clouds and atmospheric water vapor abundance. This would be extremely beneficial for understanding the relationship between cloud properties and surface convergence on the scale of a few tens of kilometers, closer to the scales at which cloud properties are determined. If STIKSCAT and these other instruments are not on the same platform, or on platforms flying in close formation, then the information on the processes that occur on the scale of individual cloud systems is lost. Further, flight with MODIS, MIMR, and AIRS/AMSU improves the joint analysis of data sets such as ocean primary production and sea surface temperature with estimates of gas transfer velocities and mixed layer depths obtained from wind stress. Co-location with MIMR is especially critical for studies of atmospheric boundary-layer dynamics and moist convergence, and this colocation will also allow an attenuation correction to the scatterometer retrievals.

The second option is to rely on the ESA M-1 platform to provide vector winds from the AMI-2 scatterometer/SAR. The AMI-2 instrument, like the AMI-1 on ERS-1, combines SAR and scatterometer measurements on one instrument, both operating

at C-band (5.3 GHz). This presents three concerns: the value of the information to be derived at C-band; the duty cycle of the instrument available for vector wind measurements; and the swath width of the instrument. For these reasons, the option of relying solely on AMI-2 entails significant risk. First, the sensitivity of backscatter on wind velocity is lower for C-band than for ffu-band (13.6 GHz), and the utility of C-band measurements will not be ascertained until at least 1992 after the launch of ERS-1 in 1991. Second; the AMI SARs are favored for operation over land targets, requiring diminished scatterometer operation within 200 km of coastal areas and ice edges. The 1200-km swath width of STIKSCAT is clearly superior to that of AMI-2 (1000 km) for global observations, and STIKSCAT's 100% duty cycle ensures that a global data set will be available for synoptic time scales. Even in the event that AMI-2 provides accurate, near-global coverage, the combination of STIKSCAT with AMI-2 will provide significantly improved sampling of the diel (diurnal) cycle, assuming significantly different crossing times. Thus we recommend that STIKSCAT be moved forward to EOS-A to provide critical measurements of wind vectors.

RECOMMENDATIONS CONCERNING HIRDLS

Major depletions in stratospheric ozone, resulting from increases in inorganic chlorine, are expected to occur in the polar regions in the lower stratosphere and globally near the stratopause during the EOS era. Ozone change is one of the high-priority, immediate goals for EOS. UARS stratospheric measurements will probably end in the 1995 period. Aside from the TOMS instruments on Earth Probes for total ozone and the NOAA SBUV-2 for ozone profiling, no global satellite capability for monitoring critical stratospheric trace species will exist after OARS, until EOS.

Both HIRDLS and SAGE III are instruments available for the EOS-A platform that can assess and monitor globally changes in trace species; however, the trace species measured and the geographic sampling are different. HIRDLS is a scanning limb viewing radiometer which retrieves temperature, ozone, the major fluorocarbons, methane nitrous oxide, nitrogen dioxide (a major nitrogen radical), nitric acid and N2O5 (the two major nitrogen reservoirs), and chlorine nitrate (a major chlorine reservoir).

In addition, the current EOS system of AIRS/AMSU temperature sounders will have only limited capability above 45 km. In the 45 - 55 km region, we will not be able to quantify ozone changes (even though SBUV-2 will measure ozone, without temperature the measurement is not quantifiable).

In the lower stratosphere, the scanning capability combined with the high vertical resolution of HIRDLS will complement AIRS/AMSU with regards to high resolution meteorological stratospheric data assimilation. This kind of assimilation is directly applicable to understanding the breakup of the ozone hole and the effect of the polar ozone depletion on mid-latitudes. Because of these capabilities, the Payload Panel recommends that HIRDLS be flown on the EOS-A platform.

RECOMMENDATIONS CONCERNING EOSP

The distribution and characterization of aerosols are major unknowns in studies of the Earth's radiative balance. EOSP combines measurements of polarization of reflected sunlight (a unique capability) with spectral coverage of the near-UV and near-IR portions of the solar spectrum so as to provide new information concerning aerosol microphysics and composition. EOSP will allow a separation of stratospheric and tropospheric aerosols, necessary to monitor their separate and different effects on climate. EOSP will be synergistic with other aerosol measurements made by MISR, because the two instruments use different techniques. This combination of instruments is especially critical for removal of aerosol effects over land areas.

In view of its importance to the study of global climate, its synergy with other EOS-A instruments, and its modest resource demands, we recommend that EOSP be added to EOS-A.

RECOMMENDATIONS CONCERNING SAGE III

The importance of monitoring stratospheric ozone and the characterization of aerosol is discussed under the recommendations concerning HIRDLS and EOSP respectively, and the SAGE III instrument can measure globally these atmospheric constituents as has been shown by its previous flight experience. However, the SAGE III geographic sampling is unique among the EOS experiments. SAGE III is a solar/lunar occultation instrument, and thereby needs a sunset or sunrise (moonset or moonrise) to take data; therefore, from a sun-synchronous polar orbit, its more frequent solar occultation measurements are in the polar regions while its less frequent lunar occultation measurements sample mid-to-low latitudes.

There is a need for measurements from SAGE III prior to EOS-A to continue the SAGE II data set, particularly for vertical structure in the long-term ozone trend. Based on the SAGE II experience, it is expected that SAGE III will be robust and self-calibrating, and therefore, capable of measuring long-term trends, as was shown by the Ozone Trends Panel, important to EOS objectives. It also has the capability to monitor volcanic aerosols which can cause serious artifacts in remotely sensed data as well as act as climate forces. However, for both the continuity of ozone measurements and for monitoring aerosols, a non-sun-synchronous orbit is preferred to provide more frequent solar occultation measurements at mid-to-low latitudes like that available from the Japanese platform, an Earth Probe, or the Space Station.

In polar orbit, SAGE III will monitor, with great vertical detail, chemical species and physical parameters important to many EOS goals including the ozone depletion problem in polar regions: key chlorine and nitrogen species, ozone, aerosols, including polar stratospheric clouds, and temperature. The more frequent polar sampling provides emphasis on the ozone depletion problem in those regions which cannot be addressed as easily from a low inclination, non-sun-synchronous orbit.

The Panel recommends an early flight of SAGE III in a low inclination orbit to address global trends and a flight on EOS-B to address polar processes.

RECOMMENDATIONS CONCERNING HIRIS

The HIRIS instrument is crucial to a broad spectrum of studies of the physical, chemical and biological processes of the land surface system, and it is particularly important to newly emerging studies of the terrestrial biosphere. HIRIS will make major contributions to our understanding of the global carbon cycle and biogeochemical cycles, generally as well as studies of anthropogenic and climatic forcing of ecosystem dynamics. HIRIS will play a critical role in the emerging and increasingly important areas of biodiversity and ecosystem change. HIRIS also provides to marine scientists, for the first time, satellite images with high spectral and spatial resolution in which not only the ship, but also the actual patch of water being studied can be clearly identified. Critical problems of global change dictate a much stronger space-based component for studies of biology, such as provided by HIRIS.

Many of the HIRIS data products and science will depend on synergism with MODIS, MISR and ITIR; reciprocally HIRIS will aid in the interpretation and analysis of data and science from these instruments. The synergism amongst the surface imagers should lead to fundamental advances in our understanding of and ability to predict changes in the biota and global biogeochemical cycles: HIRIS plays a critical role in this synergism.

However, HIRIS is an expensive instrument: what can be done if the full-up HIRIS experiment cannot be flown? We suggest three options in this undesirable eventuality. First, if significant cost savings were to result, spatial resolution could be degraded to 40 meters but not further. This loss in resolution could severely compromise the scientific value of HIRIS.

Second, we suggest that consideration be given to descoping the HIRIS mission, not just the HIRIS instrument. The HIRIS instrument might be flown on only two of the platforms, preferably EOS-A and -C. Flight on EOS-A and -C has the advantage that HIRIS data will be available from the outset for use in development of HIRIS-MODIS algorithms and it would preserve the health of the imaging spectrometry community; however, sufficient cost savings might not result. Additional savings could be realized if the launch schedule for the mission were to be delayed.

Third, if a severe and unacceptable schedule delay is required in order to establish the necessary funding profile, then HIRIS could be flown on the C- and E-platforms, or on the B-series with a redesign of that payload and a re-examination of its orbital requirements. There is disagreement within the Panel on the merits of delaying EOS-A by up to a year in order to achieve the required cost profile to accommodate our recommendation while still flying HIRIS on A- and C-Platforms, versus moving HIRIS to the C- and E-Platform. However, if moving HIRIS to C- and E-Platforms significantly risks cancellation of HIRIS, then the Panel would not endorse this action and would want to reconsider its recommendations

A shift of HIRIS to a later platform would have negative scientific consequences, and would be unacceptable if it did not completely enable the broadened science objectives of our recommended payload. The options presented are offered in the sense of compromise and should not be interpreted as any weakness in support of HIRIS objectives. Moreover, a slip in the HIRIS schedule to later platforms must be accompanied by enhanced science support during the pre-launch period and better support of the airborne program to ensure availability of AVIRIS or other high spectral-reso-

lution data at high spatial resolution, in order to allow development of the science and algorithm support.

RECOMMENDATIONS CONCERNING ALTIMETER

Ocean altimetric measurements must continue to be made in the EOS time-frame. The Europeans may provide one set of measurements. Given the sampling scale and frequency achievable from a single radar altimeter of TOPEX class, observations that resolve mesoscale variability (the eddy structure) in the ocean require the flight of two altimeter instruments on separate platforms. The Payload Panel recommends the ALT instrument for the B-observatory or a free flyer.

RECOMMENDATIONS CONCERNING GGI

GGI will make precision estimates of platform location and attitude as well as temperature measurements of the upper atmosphere. Location information is critical for correction of ranging data collected by ALT. Thus it is essential that the two instruments be co-located on the same platform. As ALT is now part of the candidate payload for EOS-B, we recommend that GGI be moved to the EOS-B platform.

However, a cost-effective implementation of GGI may be its incorporation with the platform GPS receiver and navigation system. In this case, consistency in the design of all six EOS platforms will provide this capability.

RECOMMENDATIONS CONCERNING FIELDS AND PARTICLES

The Payload Panel supports an examination of the energy inputs to the Earth System as a result of its interaction with the interplanetary medium; however, such observations need to be accomplished without constraining the accommodation of our recommended instruments.

CONSIDERATIONS OF SCHEDULE RISK

The Payload Advisory Panel recognizes that a few of the most desirable instruments have some risk in their schedule, especially AIRS, HIRIS, and MODIS-N. AIRS needs technology improvements in its detectors and coolers to achieve the needed accuracy of atmospheric sounding measurements. HIRIS is a challenging engineering undertaking, with little room for slip or error in the funding and scheduling profile. The MODIS-N Request for Proposal has not yet been released. Most of the other instruments seem well in hand, but we may run into problems later.

The Panel addressed these issues by placing the instruments in categories that reflected a mix of readiness and science issues. In case of delays in the delivery of an instrument, the Panel recommends the following response in the EOS-A schedule:

1. Delay launch by up to a year if necessary to accommodate these instruments: AMSU-A, CERES, and MODIS-N.
2. Delay launch by a few months if necessary to accommodate these instruments: AIRS, HIRIS, MIMR, MODIS-T, MOPITT/TRACER, and STIKSCAT.
3. Delay launch by a few weeks if necessary to accommodate these instruments: AMSU-B, EOSP, HIRDLS, ITIR, LIZ, MISR, and UBDCS.

In considering this recommendation seeral additional side conditions must be recognized. First, issues of multiple instrument risks as well as the question of simultaneity were not considered. Second, this recommendation represents the Panel's initial first-cut at the issue of schedule risk. Finally, we believe that further consideration of this issue is necessary and appropriate as the EOS mission proceeds.

CONSIDERATIONS RELATED TO THE EUROPEAN PAYLOAD

The Panel recognizes that there are instruments that may fly on the ESA M-1 platform in the same time frame as the EOS-A platform whose measurements may overlap with those of instruments on the A-platform. These are: MERIS, which overlaps with MODIS-N and MODIS-T; AMI-2, which overlaps with STIKSCAT; MIPAS and GOMOS, which overlap with HIRDLS and SAGE III; POLDER, which overlaps with EOSP; AATSR, which overlaps with the infrared surface- temperature-measuring function of MODIS-N; and SCIAMACHY, which overlaps with MOPITT/TRACER, HIRDLS, and SAGE III.

Some of these instruments may not fly on ESA EPOP M-1 platform. The Panel was, also, unable to evaluate the capabilities of these instruments because of insufficient information, the early stage in their development, and lack of interaction with appropriate European scientists and engineers.

From the information we have available, we believe that:

MERIS may not provide data that would meet the scientific objectives of MODIS;

AMI-2 provides complementary data to STIKSCAT, as is discussed in the section on STIKSCAT above.

For other instruments, we lack information to make any assessment. As the payload for the ESA platform is defined, we recommend that the EOS Program collect the necessary information to allow us to complete our assessment of its capabilities relative to those of EOS-A and -8.

The Panel stands ready to be of further assistance to NASA and the EOS Program in the future.

With best regards,

BERRIEN MOORE III.

Senator GORE. Thank you very much. I will hold off on further questions until the panel has concluded.

Dr. Baker, welcome. Please proceed.

STATEMENT OF DR. D. JAMES BAKER,PRESIDENT, JOINT OCEANOGRAPHIC INSTITUTIONS, INC., WASHINGTON, DC

Dr. BAKER. Thank you, Senator Gore. Thank you for this opportunity of speaking today.

As a person who has served on several advisory committees relating to the design of the EOS Program and, as you know, I was just appointed as a member of the new engineering review panel, I would like to begin by thanking you and your staff for your leadership in this area of global change and satellite measurements. I think we face tough environmental problems today and you have shown the nation the way to address these issues.

Let me focus first on the measurements that are now occurring. I think we need to emphasize the key role of operational satellites—that is, the NOAA environmental satellites and the land remote-sensing satellites, Landsat and SPOT, together with the Earth probes missions and the precursor missions. These are the satellites that we need to provide data during the 1990's.

It is absolutely essential that whatever process we have makes sure that these existing operational and research missions be kept healthy and producing data. At the same time, the studies of the 1960's through the 1980's have laid the basis for this new remote-sensing plan, the Earth- observing system. We need to put that in place. It has been designed by NASA and its partner agencies, and that is another essential aspect of our progress in remote sensing.

If the EOS core instruments can fly as planned, we would have a major improvement in our understanding of remote sensing and we would be able to make major advances in documenting global change.

I think the bottom line there is that simultaneous flight of the EOS core instruments offers the same kind of breakthrough that we achieved for the ocean with SEASAT or for the atmosphere with NIMBUS–7. It changed the way that scientists did business. I think we have the same opportunity now for terrestrial ecosystems, which is one of the areas we do not understand very well in global change.

As you know, NASA had originally planned to have two series of large satellites, EOS–A and EOS–B, each operating for 15 years. There has been criticism of that plan to have all the instruments on large satellites whose design would be frozen. Costs and timing have also been questioned. As a consequence of that, there have been two reviews that have been carried out. The recently appointed engineering review panel will also look at this system.

The NRC report looked in detail at the program, recognized the assumptions that NASA made, and supported the logic that leads to the current design of EOS–A as the most cost-effective way to fly the core set of instruments. At the same time—and I think this is important to emphasize—the committees noted that the program should allow for evolution of technology and freeze the design only at the first satellite of the series.

Now we can ask are there better ways to fly the core instruments. Suggestions have been made about flying the core instruments on several satellites, flying in tight formation rather than on one satellite. None of the reviews have addressed the issue of whether the necessary simultaneous measurements could be carried out by a set of smaller multiple platforms flying in formation. There are many technical issues that have yet to be addressed, and the costs appear to be high. This is one question which has not yet been addressed.

If the intermediate launch vehicle Atlas–IIAS were available, then there might be other ways to configure the program. But it is not clear that these would be cheaper. Current NASA studies show that it would take three Atlas–IIAS rockets to get the core instruments in orbit, and then they would have to fly in formation.

The NASA estimates that I have seen show that such an arrangement would cost more than the current one of flying the EOS–A on a single platform. At the same time, more satellites buys better reliability and options for continuity and backup. In any case, the question hangs very much on the availability of the Atlas–IIAS in the timeframe required,and one must ask the questions of whether there would be cost and delay. I am sure that this question will be addressed by the engineering review panel.

As far as EOS–B is concerned, the NRC committee, and this was supported by the Augustine committee, recommended that the issues of continuity of data, backup and reliability be addressed by the development of a more extensive strategy and long-term plan which would include the redefinition of EOS–B as a series of smaller satellites. It is my understanding that this strategy is now being developed at NASA.

The smaller satellites would measure those parameters that do not require several instruments to fly simultaneously and could serve as backups to the EOS–A instruments. The committees have pointed out that it might be possible for some of these smaller satellites to fly earlier than 1999, the current estimate for EOS–A, and thus begin to provide data sooner for documenting global change. This issue of the design of EOS–B is one that will be taken up in detail by the engineering review panel.

It is clear when we look at how we should proceed that there is a need for good documentation and a clear strategy. especially as we look at the budget process. If adequate funds are available to carry out both the Earth probes mission and the currently planned EOS–A and EOS–B missions, then we will have achieved major advances. But if funds are not available for what is considered adequate for EOS–A, the question is how will NASA and the scientific community proceed.

It is essential, and I think there is strong community support for this, that NASA as it moves ahead for EOS–A must also protect

the measurements that will come from Earth probes and the instruments proposed for EOS–B. These measurements are equally important and their flight opportunities must be protected. I do not believe that NASA can fund EOS–A at the expense of the smaller missions. The science community would simply not participate in such an unbalanced program.

We must have a budget agreement that allows for flight of both these kinds of satellites. If funds are not available to carry out the program as designed, then we face loss of measurement capability. More importantly, the loss of funds up front leads to both the delay of flight and increased costs over the long term.

Therefore, it seems to me we need to work out an arrangement to fund this. As we look at the calendar, we see a full and exciting program. If all of the instruments and satellites fly on schedule, then most of the relevant parameters for documenting and understanding global change will be done. The problem is that the calendar is not always a good indication of reality. Schedules slip for lack of funding and technical reasons, and delays have been more common than on-schedule flight during the 1980's.

If there are major delays in the 1990's, then the data needs on global change will not be met. The Federal budget process must ensure that this does not take place.

The other aspect that must be looked at is support of the operational program, the METSAT's and the Landsat's. Examples of problems that we have seen here include the GOES satellite and Landsat. This is another issue that has to be looked at carefully.

As far as overall cost is concerned, I think the bottom line is the following, and it comes from the Augustine panel report. The panel recommended that the mission-oriented part of NASA's program be designed to support two major undertakings—Mission to Planet Earth and Mission from Planet Earth. The President's 1992 budget requests $2.5 billion for Mission from Planet Earth, but only $700 million for Mission to Planet Earth.

I would submit that an increase in the Mission to Planet Earth budget to bring it closer to the Mission from Planet Earth budget might provide a NASA more responsive to needs here on Earth.

EOS, as the major part of Mission to Planet Earth, is a grand experiment aimed at achieving a quantum jump in our ability to use remote-sensing data to document and understand global change. The goal of flying a set of instruments simultaneously leads to an expensive program and involves some risk, but the payoff is high. I think we should move ahead with the program. I think the nation can afford it. I hope that NASA and the Congress together can find a way to do this so that the much-needed scientific information continues to flow and be enhanced.

Thank you.

[The prepared statement of Dr. Baker follows:]

PREPARED STATEMENT OF MR. D. JAMES BAKER

Mr. Chairman, thank you for the opportunity to address the Subcommittee on Science, Technology, and Space. I am D. James Baker, President of Joint Oceanographic Institutions Incorporated, a non-profit research management organization that plans and operates large research programs for the oceanographic community. Today I speak as an individual who has served as the Chairman of the National Research Council's Panel to review NASA's Earth Observing System in the context

of the U.S. Global Change Research Program, a member of the NASA Advisory Committee on the Future of the U.S. Space Program. I have just been appointed as a member of NASA's Earth Observing System Engineering Review Advisory Committee.

Mr. Chairman, I would like to begin by thanking you and your staff for your continued leadership in the area of global change and satellite measurements. We face tough environmental problems today; you have shown the way for our nation to address these issues. I would like to say just a word about the research programs that help put new technology into context, and then to focus on the issues of satellite measurements that make up Mission to Planet Earth, with a special focus on the Earth Observing System.

I would also like to say a good word to NASA. In these days when we seem only to hear of problems at NASA, it is important to note that the field of earth remote sensing is one that NASA pioneered and one where the achievements have continually been spectacular. From its earliest support of studies of Global Habitability, NASA has taken the lead. We should not forget that the present plans for major research programs are built on these successes.

BACKGROUND

The economic imperative of all countries to maintain and improve their quality of life have caused nations to look for better systems for documenting, understanding, and predicting global change. At the same time, there has been a recognition among scientists that the different parts of the Earth system, atmosphere, ocean, and land and living things are all interconnected. Research in Earth science has thus broadened to include a new emphasis on the coupling among physical, chemical, and biological processes on Earth, leading to the concept of "Earth System Science".

Major research programs have been put into place to study global change. Among these are the World Climate Program and the International Geosphere-Biosphere Program. The work of the World Climate Program was reviewed at the Second World Climate Conference held at the end of 1990. The Conference recommended an expanded climate program with emphasis on delivery of data as well as research and strongly supported the development of a Global Climate Observing System, which will have an important satellite component. In 1992, a major international conference on Environment and Development will take place in Rio de Janeiro sponsored by the United Nations. This conference, the follow-on to the Stockholm conference of 1972 which led to the establishment of a number of new UN agencies for the environment, will be the focus for applications of science to environmental issues.

SATELLITE SYSTEMS OF THE 1990'S

The satellite systems of the 1990s are those planned during the 1980s to address major Earth observational needs. These satellite programs will all provide data for the programs that are needed to address global change. From the schedules of planned measurements, we can see several important points: first is the key role of the operational satellites, the NOAA environmental satellites and the land remote sensing satellites Landsat and Spot. It is essential that these be kept healthy and producing data. I will have some recommendations about the operational programs at the end. Second, there are a number of missions to be flown in the 1990s that will provide important new information. NASA has begun a new series of satellites, called Earth Probes, that will address many of these issues.

The Upper Atmosphere Research Satellite UARS to fly in 1991 will provide stratospheric chemistry measurements. The European Space Agency's ERS-1 to be launched in 1991 and its follow-on, planned for 1994, will measure a variety of ocean and land surface parameters. SPOT, the land-viewing mission operated by France, is a continuing program. TOPEOSEIDON, the joint U.S./French mission for precision altimetry will fly in 1992 to provide data for ocean circulation as part of the World Ocean Circulation Experiment. Altimetry will be continued by the U.S. Navy Geosat Follow-On, and possibly by a new set of altimeter satellites (discussed below).

The Sea-Viewing Wide Field Sensor will fly in 1993 or 1994 on a commercial spacecraft to provide ocean color data for the Joint Global Ocean Flux Study and commercial fisheries users. The NASA scatterometer, an ozone monitor, and an ocean color instrument are a few of the instruments on the Japanese ADEOS satellite that will fly in 1996 to help continue ocean and atmosphere measurements in the 1990s. Of particular importance for radiation measurements is the SCARAB

mission proposed by the French and Soviet Union; this will continue the ERBE studies.

The Tropical Rainfall Measuring Mission, scheduled for 1996, will use microwave instrumentation to monitor rain in the tropics and will carry a radiation instrument to continue the ERBE studies. Atmospheric measurements will also be carried out from instruments on the Space Shuttle; imaging radars, and atmospheric chemistry and ozone are illustrated. Shuttle measurements will be the only tropospheric chemistry studies until such instruments are flown as part of the Earth Observing System.

The Laser Geodynamics Satellite-II, a mirror satellite jointly operated between the U.S. and Italy and scheduled for launch in 1991, will be the continuation of current programs which allow precision positioning from Earth and observations of continental drift with possible earthquake precursor warning. Satellites with synthetic aperture radar are planned by Canada and Japan early in the decade; these will continue and augment the measurements by ERS-1 and 2. Plans, but not firm funding, are in place for measurements of the Earth's magnetic and gravity fields. Each of these would be joint between the U.S. and France or ESA.

There are plans under discussion now in the U.S. and France for flight of altimeters later in the 1990s, after ERS-1 and ERS-2. For example, the French Space Agency CNES is considering an independent altimetric small satellite series using the experience gained with the DORIS tracking system and the French solid-state altimeter used on TOPEOSEIDON. This plan is similar to the U.S. Navy plan for a ten-year three- satellite altimetry program to follow the Geosat program. The Navy satellite would be a "light sat" weighing 300 pounds, so that it could be launched from a Pegasus rocket. It would have a single frequency altimeter, radiometer, and a GPS tracking system. The first satellite would be launched in 1995. Following this program the Navy hopes to transition altimeter instrumentation to a future DMSP satellite to continue altimetry as an operational measurement.

The studies of the 1960s through the 1980s have led to a set of operational and research missions for the 1990s that will lay the basis for a comprehensive program for global change observations for the 21st century. We will need to continue the measurements that are now in place well into the 21st century to establish long-term data sets. At the same time, we need to recognize the limitations of past measurements and take a new step in remote sensing to improve the measurements so that quantitative interpretation is possible on a regular basis. NASA and its partner space agencies have designed the Earth Observing System to meet these two needs.

MISSION TO PLANET EARTH OBSERVING SYSTEM

EOS is the first step in the program "Mission to Planet Earth": a long-term series of polar-orbiting and geostationary satellites for study of global change. EOS has three objectives: the creation of an integrated Earth observing system, the development of a comprehensive data and information system, and the assembly of a long-term global data base.

In terms of the need for long-term data sets, EOS is being designed to be complementary to the Earth Probes; both are planned to be long-term systems. At present, EOS is designed as a series of satellites that would first be launched in the late 1990s (1998 or 1999) and would continue for at least 1; years. Some of the instruments to be carried on EOS spacecraft are considered as "pre-operational"; that is, they are being tested for use on the regular operational satellites operated by NOAA. Thus EOS will serve as one way to provide the research and development for the operational program. At the same time, the long-term data sets from EOS itself will be key to studies of global change.

But it is not only in long-term data sets that EOS promises its major achievement. The remote sensing community is in general agreement that in order to make the major advances we need to move beyond our limited knowledge of atmospheric and surface effects on transmitted signals, in other words to do the atmospheric and surface physics quantitatively and right, we must fly a number of instruments simultaneously. The 1988 NASA Earth System Science Committee report (A Closer View) emphasized this point: extensive experience has shown that merging uncoordinated data streams is painful, slow, costly, and frequently ineffective. Coregistering images, reconciling navigation data, interpolations onto common frames of reference, and developing procedures for allow for lack of synchronization and differences in atmospheric transmissivity and illumination angle is difficult. There are great benefits to integrating different instruments on the same platform. This integration is one of the design factors that drives EOS planning.

Thus there are two major points addressed by EOS: the need for simultaneous measurement by several instruments (the core instruments), and the need for a va-

riety of parameters to be measured. The long life of the program provides for long-term continuity; an essential element.

The Earth Observing System measurements can be divided into three parts: Surface measurements on land and ocean, atmospheric measurements in the troposphere and stratosphere, and solar measurements. The design of the EOS instruments incorporates several new developments that are essential for understanding and documenting global change. For example, the Moderate Resolution Imaging Spectrometer (MODIS), is designed to have high spectral resolution so that it.can be tuned to image land and ocean equally well as well as to measure and correct for atmospheric effects.

The plans for the first EOS platform, called EOS-A, provide for flying several instruments simultaneously and thus will allow the necessary corrections to be made for the first time in an accurate way. The necessary simultaneous measurements in this scenario would come from a set of core instruments that measure radiation, sound the atmosphere, and image the surface. If the EOS core instruments can fly as planned, we would have a major improvement in our understanding of remote sensing, and hence would be able to make major advances in documenting global change. Without this simultaneous flight, we will always be limited by what can be done with remote sensing data from sensors flown individually.

NASA originally planned to have two series of large satellites, EOS-A and EOS-B, each operating for a period of IS years. The series of two large satellites makes it one of the most expensive Earth sensing programs ever operated. There has been criticism of the plan to have all the instruments on large satellites, whose design would be frozen at the outset of the program. As a consequence of this criticism, two review committees have recently examined the EOS program: a committee appointed by the National Research Council, and the Advisory Committee on the Future of the U.S. Space Program.

The NRC report and the Advisory Committee of the Future of the Space Program noted the assumptions that were used and supported the arguments, based on these assumptions, that lead to the current design of EOS-A. At the same time the Committees noted that the program should allow for evolution of technology and thus freeze the design of only the first satellite in the series. Moreover the Committees noted that the continuity, backup, and reliability were not adequately addressed in the plans presented.

The Committees recommended that these issues be addressed by the development of a more extensive strategy and long-term plan which would include the redefinition of EOS-B as a series of smaller satellites. These smaller satellites would measure those parameters not requiring several instruments to fly simultaneously, and could serve as back-ups for some of the more important EOS-A instruments. The Committees also pointed out that it might be possible for some of these smaller satellites to fly earlier than 1998 or 1999, the current estimate for EOS-A, and thus begin to provide data sooner for global change.

With one large satellite and a set of smaller ones, measurement simultaneity, breadth of parameters, continuity, and backup could all be addressed. The mix of different size spacecraft was considered to be the best for the program. The Committees also noted that EOS, designed as a 15-year mission, is more like an operational program than a short-term, one-time research mission, and thus must be treated differently in terms of documentation, formal procedures, etc.

EOS DATA AND INFORMATION SYSTEM

The data system will produce a data stream from EOS that will be large, about one Library of Congress per day. But it will not be unmanageable, since the data stream is split to many users early on. It should be noted that the division of funding between satellite hardware and data systems has been an issue, since funding for satellite hardware can dominate and erode the funding for the data systems. It has not been easy for many users to access data, either for reasons of cost or because data are not available in formats that can easily be used. Recognition of this problem has been an important part of the plans for NASA's Earth Observing System. In recognition of the large data volume to come from that program NASA plans to allocate 40 percent of the cost of the program to spacecraft hardware and 60 percent for ground-based activities, including the Earth Observing System Data and Information System and science investigations. This ratio of funding is the reverse of the normal mission, where the majority of funding goes to spacecraft and instruments.

Congress has emphasized the importance of the data system by putting the funding in a separate line item. NASA has also already begun funding of the data system, so that the community can learn how to operate with such a large data stream.

The review committees have strongly supported NASA's plans for the data system, emphasizing that it is essential that there be a continual interaction with the user community in the development of the data system.

ISSUES UNDER DISCUSSION

First, the estimated cost of the program, now estimated to be about 2 Billion per year, has led to questions about whether the program could be done in a cheaper way. Putting many instruments on one large satellite has led to criticism about possible catastrophic loss. The original launch date: close to the mid-1990s, has been slipping closer to the year 2000, thus delaying the information we need for global change. Could the instruments be flown sooner? Suggestions have been made about flying the core instruments on several satellites flying in tight formation rather than on one satellite. The possibility of the availability of intermediate-class launch vehicles, such as the Atlas IIAS, has also been raised. Is it possible or feasible to reconfigure EOS to meet these points and possibilities?

If the Atlas IIAS were available, then there might be other ways to configure the program, but it is not clear that any of these would be cheaper. Current NASA studies show that it would take three Atlas IIAS rockets to get the core instruments into orbit on three satellites, which would then have to fly in formation. The NASA estimates I have seen show that such an arrangement would cost more than the current one of flying EOS-A on a single platform. At the same time, more satellites buys better reliability and options for continuity and backup. In any case, the question hangs very much on the availability of the Atlas IIAS in the time frame required.

The review committees noted that a healthy and properly designed Earth Probes program and a properly designed series of spacecraft for EOS-B would help address issues of continuity and backup. Neither study addressed the issue of whether the necessary simultaneous measurements could be carried out by a set of smaller multiple platforms flying in formation, but there are many technical issues yet to be addressed for this kind of configuration and the costs also appear to be high.

As far as measurements earlier in the decade are concerned, it is essential that NASA, as it moves ahead with EOS-A, protect the measurements that will come from Earth Probes and the instruments proposed for EOS-B. These measurements are equally important, and their flight opportunities must be protected. NASA cannot fund EOS-A at the expense of the smaller missions—the science community would simply not support such an unbalanced program.

Second, the NRC report focused on the need for adequate documentation, development of a clear strategy for evolution of the program and the process by which instruments are selected. The need for documentation and a clear strategy is especially important when we consider the budget process. If adequate funds are available to carry out the planned Earth Probes missions and the currently planned EOS-A mission, then we will have achieved major advances. But if funds are cut below what is considered adequate for EOS-A, how will NASA proceed? Unless a clear strategy is developed which shows the quantitative effects of budget constraints, NASA may be faced with others making decisions on the technical aspects of the program, as just happened with Space Station.

INTERNATIONAL PARTICIPATION

It is clear that activities outside the U.S. are vigorous and growing. The World Weather Watch satellites involve the U.S., Europe, Japan, India, and the U.S.S.R. Other countries are building space capabilities rapidly. For example, on September 3, 1990, the People's Republic of China launched their second experimental meteorological satellite into a sun-synchronous orbit. The satellite, called Feng Yun 1B (Wind-Cloud), is now transmitting both visible and infrared weather and land images. The land satellites include the U.S. Europe, France, U.S.S.R., China, Brazil, India, Japan, Italy.

As far as EOS is concerned, design issues are currently being discussed in Europe and Japan as they consider their contributions. The size and orbit of the Japanese platform is still under discussion, and they are negotiating which instruments they will carry. In Europe, the polar platform discussion is taking place in the context of the whole space program ranging from the proposed HERMES shuttle to launch vehicles. At present, the relevant ESA program encompasses a variety of plans for flight of both earth observations and space science instruments on a relatively large polar platform. The possibility of replacing the this polar platform with a series of smaller dedicated missions all flying separately is also under discussion. The US will have to follow these developments closely to ensure that the full range of parameters to be measured is covered by the various plans under discussion.

ISSUES TO BE FACED

Issues for current operational systems include technical issues ranging from instrument failure to replacement of old technology with new technology, inadequate funding, the need for multi-agency support of operations and the research and development needed for improving operations, and an inadequate system for archiving and distributing data and information.

The technical issues fall into two categories, one which is obvious, the problem of instrument failure. The development of new, more reliable systems is aimed at reducing the failure rate. Another problem which is not so obvious is that many research spacecraft continue to operate well beyond their initial specifications; the instruments aboard are not always designed for longer lifetimes and there are often no plans for long term calibration. The Solar Mesosphere Explorer (SME), launched in 1981, was expected to last for one year but operated for five years. Nimbus-7 is still operating after 12 years. Fortunately, the data from these satellite instruments have proved to be useful, but long-term calibration is an important aspect of data collection for global change.

One of the major problems at the moment is that there is inadequate funding for the development of new operational systems. A great deal of research and development needs to be done to ensure that replacement operational systems embody the best and most reliable new technology. NASA's charter includes the development of new space capabilities, but NASA's role in the research and development for operational environmental satellites has diminished in recent years. For this reason, the report of the Advisory Committee on the Future of the U.S. Space Program recommended that "NASA should reestablish research and development in support of environmental satellites to meet NOAA-stated requirements. NOAA, for its part, must budget adequately to finance the operational costs of spacecraft and instrument, as well as related day-to-day support activities." If this recommendation is followed by the two agencies, and adequate funds are provided, then operational satellites will be put on a firmer footing.

A second issue is the support of the land-sensing satellites Landsat. NASA's experimental Landsat program was transferred to the Commerce Department in 1983 with the expectation that the operation could be commercialized profitably. Virtually all parties to that expectation now agree, and international experiences verify, that full commercialization of Landsat is not feasible for the foreseeable future. Moreover, the funding required to sustain the transfer has been subject to an annual threat of terminations. The Advisory Committee on the Future of the U.S. Space program noted that action must be taken to remedy this problem, or the U.S. shall lose both this important data and leadership in remote sensing—the latter already under serious challenge.

It is good to note that the President's budget for FY 1992 states that acquisition of data from land remote sensing satellites is an important element in understanding global change. The Administration is apparently fully committed to operating Landsats 4 and 5 as long as they are the only operational Landsat satellites, and to completing the development and launch of Landsat-6. The budget proposes $17 million for the Department of Commerce to cover Landsats 4 and 5 through August of 1992, when Landsat 6 is expected to become operational. The hope is that Landsat 6 will be able to be operated at the expense of the Earth Observing Satellite Company (EOSAT).

As we look at the calendar, we see a full and exciting program. If all of these instruments and satellites fly on schedule, then most of the relevant parameters for documenting and understanding monitoring global change (except for the geophysical magnetic and gravity fields) will be covered during the 1990s. The problem is that the calendar is not always a good reflection of reality. Schedules slip for lack of funding and technical reasons and delays have been more common than on-schedule flights during the 1980s. If there are major delays in the 1990s, then the data needs of global change will not be met. The federal global change budget process must ensure that such delays do not take place.

A second issue involves the coordination between satellite measurements and field programs. Since most of the science goals require a combination of satellite and in situ studies, it is essential that these be coordinated. But once set in place, field programs involving contributions from several countries are difficult to change because of satellite delays, and hence the two can end up not being simultaneous.

A good example of the problems of scheduling can be seen in the planning for a major study of biogeochemical cycles in the ocean' for the early 1990s: the Joint Global Ocean Flux Study. Measurements of ocean color by satellite to document biological productivity are an important part of this program. At the time the original field study was being put into place, it was anticipated that an ocean color satellite

would be in place by the early 1990s. The field studies were planned, and have now begun. But it now appears that the ocean color measurements will not be available until 1993 or 1994 at the earliest, well after some of the major field studies. Since important objectives of the study cannot be met unless data is taken simultaneously from space and in situ, the only thing that can be done is either lengthen the experiment or delay it until the satellite measurements are possible. It is to NASA's credit that they have pushed for a new way of doing business for this satellite, by involving the private sector to provide a data stream.

CONCLUSION

The best summary comes from the report of the Advisory Committee on the Future of the U.S. Space Program. The Committee supported the concept of simultaneous flight of instruments and the requirement for a large spacecraft, which is less costly on a per instrument basis. The Committee also supported the NRC report which noted that the design of EOS must involve a variety of different spacecraft to meet so complex a set of requirement. In the end a combination of different size spacecraft and surface-based platforms will be needed.

The Committee also noted that alternative approaches should be carefully examined so that the optimum approach can be selected to meet scientific objectives with continuity, reliability, and affordability. Particular diligence will be required to assure that the complexity of EOS is controlled. The Committee recommended that the multi-decade set of projects known as Mission to Planet Earth be conducted as a continually evolving program rather than as a mission whose design is frozen in time. It also emphasized that a combination of different size spacecraft appears to be the most appropriate to meet the needs of simultaneity, accuracy, continuity and robustness.

The Committee recommended that the "mission-oriented" portion of NASA's program be designed to support two major undertakings: Mission to Planet Earth and Mission from Planet Earth. It is interesting to note that the President's FY 1992 budget requests $0.77 billion for Mission to Planet Earth, but more than three times as much, $2.5 billion, for Mission from Planet Earth. Are these priorities right?

EOS, as the major part of Mission to Planet Earth, is a grand experiment, aimed at achieving a quantum jump in our ability to use remote sensing data to document and understand global change. The goal of flying a set of key instruments simultaneously leads to an expensive program that involves some risk, but the payoff is high. Thus it is important to move ahead with the program. I hope that NASA and congress together can find a way to do this so that the much needed scientific information continues to flow and to be enhanced. Thank you very much.

Senator GORE. Thank you. Dr. MacDonald, we appreciate you appearing on short notice, and we look forward to what you have to say.

STATEMENT OF DR. GORDON J. MacDONALD, INSTITUTE ON GLOBAL CONFLICT AND COOPERATION, UNIVERSITY OF CALIFORNIA AT SAN DIEGO

Dr. MACDONALD. I certainly welcome and appreciate this opportunity to discuss what clearly is a critically important issue in attempting to understand global change.

Senator GORE. Would you point that microphone toward you, if you would?

Dr. MACDONALD. EOS has the potential to improve our view of the long-term behavior of the atmosphere and its interaction with the ocean and biosphere. While I recognize the potential and the goals which EOS has set for itself, I have a number of deep concerns. I have grouped these under five categories—data management, timeliness, ground-based observation, human resources, and the issue of a single platform. I will comment briefly on each of these.

Data management. The volume and variety of data derived from EOS and the variety of users and potential users, make the data management problem of EOS unprecedented. I can say this from

almost two decades of experience as chief scientist of MITRE, where I dealt with a wide variety of very large data bases for the defense and intelligence communities.

The problems are related to architecture and software development. The technology—the hardware—is available currently or will be available in an appropriate time scale. But the architecture—that is, how the data base is structured—is of utmost importance and, for example, it concerns me greatly that the decision has already been made that there be seven DAAC's based on discipline.

While I recognize some of the reasons for such a decision, that already puts a constraint on what the overall architecture is going to be and how it is to be implemented. Our experience with large data bases says that data base management systems have to develop incrementally and adapt to the users, and by users I mean not the scientific community meeting in a committee that puts out a list of wishes, but users who actually will be at the terminals practicing on data, looking at prototype data bases and feeding this information back to the contractor or manager of the data system.

A sure recipe for disaster—and I have seen it over and over again—is a turnkey operation where detailed specifications are set out in the RFP. The contractor then works for a number of years and turns over a product, having not had the benefit of day-to-day interaction with the user. The product often is totally useless.

It requires a cooperative venture between those who are actually building the architecture, writing the software, and developing the algorithms, not only the principal investigators and their colleagues, but also the wide variety of other users who will be making use of the data as it develops.

The second issue is timeliness. One of the important aspects of any system, particularly one dealing with climate change, is the ability to react quickly to new discoveries in the case. We have seen the impact of new discoveries in the ozone depletion question.

In climate change we have already had a number of surprises—for example, Ramanathan's observation of the supergreenhouse effect in the western tropical ocean. This phenomenon clearly needs to be understood. If RPV's, remotely piloted vehicles, and/or a small satellite were available for rapid launch, then those phenomena might be analyzed and looked at in a small period of time rather than waiting for the next Earth radiation budget experiment, which is scheduled for TRIM and might be in 1996 or 1997.

This brings up the whole question of the importance of remotely piloted vehicles. I am delighted to hear that NASA does have a small program—I think it is centered at the Ames Research Center—to look at potential for RPV's. Clearly a lot has been done within the defense community.

That experience should be made use of, although some of the RPV's developed in the defense community are too large and expensive for the kind of programs needed to support climate observations. But there are, either in design or in early testing, relatively inexpensive RPV's that could be employed to analyze a number of problems, particularly those related to cloud physics and the impact of clouds on the radiative balance.

A second issue with timeliness is the need to maintain continuity in observations. The fact that we are going to have a several-year

gap in the radiation budget measurements is, of course, extremely unfortunate. I think one needs to look at the possibility of trying to fill that gap even before the launching of TRIM.

The third area is ground-based support. Many of the observations that can be made from space are valuable without having ground-based observations. But that value can be very much enhanced by obtaining ground truth, in particular the understanding of clouds. Their effect on the radiative balance requires both observations from the ground looking up, observations from space looking down, and observations from airborne vehicles, possibly RPV's, that are able to sample clouds—to enter the region, to fly immediately above clouds.

There are a number of programs in other parts of government, and I think, for example, in the case of clouds of the atmospheric radiation measurement program of the Department of Energy that could add very substantially to the goals of EOS.

The fourth area is are we going to have the human resources available—that is, the scientists—to analyze and understand the vast avalanche of data that will commence following the first launch of the first platform. As the hardware demands for EOS become heavy and the budget shifts, there will be concern and less attention given to the development and continuation of programs and support of scientists, particularly to support of those scientists at academic institutions who will be training the next generation.

Having lived through the early days of NASA's lunar and planetary program, one of that program's highlights was the emphasis on graduate fellowships, postdocs, and so forth. While there is a smaller program currently in place at NASA, I think it is insufficient to build up the scientific cadre required to support EOS.

Fifth is the issue of a single platform. The lack of resilience can really be attributed to the placement of all of the proposed instruments on one large platform. Not only does this lead to greater technical complexity, but all the instruments and spacecraft systems must also be developed in parallel, leading to a highly interactive schedule and cost risk.

Now, having these concerns, I am pleased by the number of developments. I think an in-depth examination of what can be gained by a small satellite program along the lines outlined by Jim Hansen and his colleagues—I might just note that clearly you played a very important role in bringing the issues to a head through your series of workshops in which Jim Hansen and others participated, and I think many of the ideas expressed and issues in the Science and Technology article really developed through those sessions.

Now a number of other things are happening. JASON, a group of scientists who work primarily on national security problems, had a 1-week winter look at the potentials of smaller satellites, taking into account the technologies that are available in the military communities. A much more in-depth analysis by JASON will be carried out this summer, looking specifically at what can be gained through small satellites using military technology as well as technology currently available in the civilian sector.

I understand that the Committee on Earth and Environmental Sciences is carrying out an analysis of what can be done with re-

motely piloted vehicles, and a draft of that report is, I think, due May 1.

A very important development is the initiative you had such a large part in—that is, the strategic environment research and development program, which opens up the possibility, which has not yet been acted upon in any meaningful way, of using not only the data that has been collected in the defense and intelligence communities but also some of their systems, instrumentation and so forth—data secured by the defense meteorological satellite, by the nuclear detection satellites. All have applicability and their usefulness should be analyzed in some detail.

The program to develop LIGHTSAT or a less expensive launch vehicle has direct applicability to moving forward with a small satellite program.

In sum, I think it is appropriate to ask the Committee on Earth and Environmental Studies, which does have this coordinating responsibility, to come forward with a much more detailed plan for an integrated satellite/aircraft/remotely piloted vehicle/ground-based program. There is emphasis and a lot of discussion on the satellite part, and obviously, since it is by far the most expensive, that emphasis is well taken.

But all of these components have to work together and I think such a review should address the issues that I have raised—the question of data management, the timeliness, the ground truth, the supporting human resources, and the lack of resilience in the single platform configuration for EOS–A.

Thank you very much.

Senator GORE. Thank you very much. I certainly appreciate your testimony.

Just to begin the questions, Dr. MacDonald, with something you said in your statement about the radiation budget measurements and the gap now anticipated, how would you fill that gap?

Dr. MACDONALD. I think the best way of filling the gap would be to proceed with something along the lines that Hansen recommended, repeating the ERBE observations launched on the small satellite, and I would also add, of course, the SAGE instrumentation on that payload.

Senator GORE. Dr. Baker, Dr. Moore, do either of you wish to comment on that?

Dr. BAKER. It is my understanding that NASA currently plans to put the radiation budget instrument and the SAGE instrument on the TRIM satellite, which would be the earliest thing that could be done with the existing satellites. I think that is the current plan. But, as Dr. MacDonald pointed out, I think that launch is not until 1996 or 1997.

Senator GORE. So, the gap would be how long?

Dr. MACDONALD. The gap is from last year to 1996–97. It will be 6 or 7 years. I think that one can certainly get a much shorter turnaround time, perhaps using LIGHTSAT or some other available system out of the military in terms of launch vehicle. A 2-year turnaround time, given that the instruments are already developed, is certainly not out of the question.

Dr. BAKER. Let me just comment. There is a Soviet-French program called SCARAB—the scanning radiometer—that I believe is scheduled to fly this year or next year.

Senator GORE. Will that fill the gap?

Dr. BAKER. It partially fills the gap, I believe.

Dr. MACDONALD. I think there are great concerns about the calibration of that instrument.

Dr. BAKER. Questions about the instrument have not been resolved. I do not think we have fully understood all the details of the instrument, but it will be a radiation instrument.

Dr. MOORE. I was just going to comment on that, that we also have to be reasonable. To say how quickly one can get the RFP's out and get instruments built and launchers obtained, I think the French effort is something that should not be ignored, even with questions on calibration.

Senator GORE. You also said, Dr. MacDonald, that it is dangerous to design the data system as a turnkey operation, and you propose instead—I am not sure you laid out specifically what you would propose instead, but in general terms you proposed that the users be an integral part of designing and evolving the information system.

How would that work?

Dr. MACDONALD. I think the statement made by Dr. Fisk with respect to the Japanese request to include at an early stage, let us say, the TRIM data in the EOSDIS is an essential first step. But you start taking existing data, including the Landsat data, data that is coming out of the TOMS program, and the other Earth probes, and have the investigators and other users interact continually with the contractor with major responsibility for putting the system together.

In other procurements of this sort what often has happened is you have representatives of the contractors actually sitting in the laboratories or offices of the people who are using the data, seeing how it is being used and what the requirements are on a day-to-day basis, feeding that information back into the design team so that it is an ongoing process.

Taking people who do not have experience—they are very good at computer science and related topics but do not have experience of how a scientist works with data derived from space—there is a gap in communication, and that gap needs to be filled by continual interaction between the scientists and the designers.

Senator GORE. Dr. Moore.

Dr. MOORE. Two comments. One, I think almost all of the points that Dr. MacDonald is making were included in the various reports of the study committees done by the scientific community that were delivered to NASA—the so-called Dozier report being just one.

Second, as a principal investigator in the EOS mission and also as director of the laboratory at New Hampshire, we have been visited extensively and repeatedly by all of the contractors. They have stayed with us for days—they are almost in the way sometimes—looking at what we are doing. And I know in talking with the other principal investigators, both in this country and abroad, that Hughes and TRW and General Electric have all been paying visits to those laboratories as well.

I certainly concur. It is not that I am not concurring. I think, though, that the process is actually going in that direction, perhaps having learned from the mistakes of the past that Dr. MacDonald spoke about.

Senator GORE. Now, Dr. Moore, you have noted that the changing of the instrument package for EOS–A has made the Landsat data record even more valuable. I interrupted your statement to ask if you were aware of how limited that data record has recently become, with the change in policy to turn the cameras on only when McDonald's restaurants or some other commercial user indicates an interest in getting a picture of some particularly busy traffic intersection.

Very few people are asking for pictures of what is happening to the rain forest. I do not think I am overstating that. If I am, I welcome a correction. But is that not a major problem if we are going to rely on the Landsat record to fill that gap due to the reconfiguration of the EOS–A instrument package?

Dr. MOORE. You are certainly correct. Let me amplify on it in two areas. A number of us who have been concerned about the issue of tropical deforestation have recognized that and that the Landsat data was central and therefore we have established cooperative relationships, for instance, with Brazil and the Brazilian space agency because they are receiving the data.

We will be working cooperatively with them. However, that does not address the needs of what is happening to the forests of central Africa, the forests of Thailand, Indonesia, all of southeast Asia, the forests of India. So, in some sense there is some good news, but there is also the bad news that you spoke about.

I am hopeful that NASA and the private sector or the Federal Government generally and the scientific community can find a solution to this. It goes beyond just the current data. In some sense it has raised anew the importance of getting the whole program straightened out and then seeing a follow-on Landsat–6 and Landsat–7.

We have also been using a lot of SPOT take. But for a number of studies SPOT is a less capable instrument. The French satellite is a less capable instrument than for the——

Senator GORE. Why is that?

Dr. MOORE. The spectral coverage.

Senator GORE. Dr. Fisk, do you want to join us back at the witness table, if you do not mind, just to help us pursue this question for a moment?

Feel free to consult liberally with your staff since they are not at the table with you.

Dr. FISK. They all left. I am on my own.

Senator GORE. Could NASA become a Landsat customer and order pictures to supplement the record being compiled for EOSDIS, notwithstanding the fact that it is not a NASA satellite?

Dr. FISK. I am not aware of any impediment other than financial to do so.

There was a question Senator Pressler asked me and I am not sure—perhaps you were out of the room when I answered it, but let me just repeat the answer.

EOSAT management has changed recently, and we have started some dialog with them that has been quite encouraging. I do not want to predict how it is going to go, but the attitude on these issues has been a very positive one, and I am kind of encouraged by those discussions. That would obviously be very helpful if they can change some of the previous corporate policies on the collection and dissemination of data.

Senator GORE. Well, this subcommittee pushed them very hard on the pricing policy, and, as I noted earlier, they have responded. I agree with you, Dr. Fisk, that the attitude there seems to be much more positive and constructive and amenable to dialog. I would urge NASA to continue a dialog.

I would like to ask you to specifically inquire—and if you could provide the responses to the subcommittee it would be most appreciated—what would it cost for NASA to become a customer of Landsat imagery, to collect a data set in response to the configurations suggested by your user panel, to get the data on what is happening to the land surface area of the Earth, what is happening in deforestation, and several related questions—perhaps what is happening to snow cover in the tundra areas.

The NASA satellite analysis of temperature in Huntsville showed, for example, that last March temperatures in Siberia were an average of 18 degrees Fahrenheit warmer than any previous March on record. What were the consequences for the Albedo in the northern parts of Siberia? These are examples that illustrate the need for a good record of what is happening to the surface of the Earth.

If we are going to wait until 1998 to get that and now we are going to wait until EOS–B to get that, then this unique Landsat record becomes even more important.

I agree with the comments made by Dr. Moore earlier. Now, if we were all sitting around and saying now what if we could get a satellite up there right now very quickly that would take pictures of the land surface area and tell us that information, I could well imagine that it would be a part of Mission to Planet Earth. It would be part of your program here. People would say, oh, we have that covered. We are going to put up Landsat. We are going to get that imagery early on.

You are going to be very pleased with how quickly we can answer those questions because we will be launching that. But the fact that it is already there and all we have to do is turn the camera on somehow is an impediment to getting the data more quickly.

With the budget pressures, of course, it is not all that mysterious, but if you could give us an estimate of how much it would cost in the budget for NASA to become a customer and get that imagery in consultation with your user panel, we would appreciate that.

Dr. FISK. We will take a crack at it.

[The information referred to follows:]

NASA agrees with the National Research Council (NRC) assessment of the importance of both past and future Landsat data as part of the data set for global change research. NASA is working with the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), which manages the Landsat system, and the Earth Observation Satellite Company (EOSAT), which operates the system for NOAA, to facilitate the most complete access for researchers to Landsat data permitted by current law. NASA intends to establish a Pathfinder data activity

to process the Multi-Spectral Scanner (MSS) data recently released by EOSAT for research use. We are beginning an assessment of the scope of processing required for the MSS data, which includes the entire MSS data set except for the last 2 years, and of the resources needed to include this data in the EOS Data and Information System (EOSDIS). In addition, recent meetings between NASA and EOSAT officials explored other issues related to future research availability of Landsat data. Follow-on meetings have been scheduled in the coming months to continue this dialog.

Our current approach is to fund individual research projects which may include Landsat data as a component. Increased use of Landsat data would either result from increased use by such researchers or by NASA directly purchasing large blocks of data on its own. A general cost estimate would depend on the final arrangements concluded with EOSAT.

NASA believes the most effective research approach would be to make all Landsat data available to research users at the marginal cost of reproduction, perhaps through the EROS Data Center, operated by USGS, which has been designated as a Distributed Active Archive Center within the EOSDIS. This would ensure the widest availability of data to earth science researchers and would expand the number of investigations using Landsat data.

Senator GORE. Do you have any visceral objections to that suggestion?

Dr. FISK. No, I do not.

Senator GORE. I mean any visceral objections to the idea of NASA buying that data and using it to help construct the overall data set for EOSDIS?

Dr. FISK. The only visceral objection I have is one that says if the existing commercial rates were to apply here, then I say I am suddenly in the business of funding the stockholders of the EOSAT Corp. and I object to that. If we can find a way to do this at essentially cost or some small profit, then I think it is a very valuable thing to do.

Senator GORE. Well, let us do that.

Dr. MacDonald, you talked about manpower, and earlier Dr. Fisk responded to a question I put to him by saying that NASA has in its current budget plans to fund 150 graduate students.

Dr. FISK. These are special fellowships. There is also the normal support for research graduate students as part of our grants program through the specialty.

Senator GORE. Does that answer the concern you were raising, or are you talking about something beyond that?

Dr. MACDONALD. Yes. I think it is going to take a program well beyond that, particularly in those areas where NASA in the past has not had a great deal of interaction. If you look at ecology areas and the biological sciences, agricultural sciences, and so forth, I think there is a very great need to build up capabilities there as well as within the more traditional fields of geology, geophysics and meteorology and so forth.

Senator GORE. Do you want to comment, Dr. Fisk?

Dr. FISK. Only that I would not underestimate the number of students. I would have to dig the number out of my memory—perhaps for the record—but NASA's space science program, of which earth science is a part, probably supports in the neighborhood of several thousand graduate students each year, and those people are people who are supported with research grants and contracts to professors at universities.

Obviously 150, if that was all it was, would be inadequate. Would 300 be a better number? Sure. Would 500 be a better number?

Maybe so. But do not take that 150 as the only number; there are many other graduate programs.

Senator GORE. Dr. Moore, you stated that the principal driver for EOS in terms of time is the development of instruments such as the MODIS–T and MODIS–N, not really the size of the platform. If that is the case, why then could you not fly certain instruments that would be available first and then fly MODIS at a later date? Why does it not make sense to gather as much of the data as possible, as early as possible?

Dr. MOORE. Two things. First of all, I agree with you. That is why we were looking to fly CERES and SAGE–3 earlier. They do not in some sense require all of the capabilities that are going to be on EOS–A. So, I think that there are going to be these opportunities that would allow getting these instruments up.

However, there are certain key things that we want to get at that require such things as MODIS–N and MODIS–T. I mean, the whole question of uptake of carbon dioxide is going to be tied to trying to understand primary production in the ocean and in a sense some of those instruments that we most want happen to be the rate limiters.

If we had a converse situation, if it were a less high visibility instrument or less central instrument that was the cost driver or the one that we were expecting in 1998 or 1999 and we had MODIS–T and MODIS–N ready to go in 1995 or 1996, I think the argument would be totally different. But, regrettably, these major advances on AVHRR or the SEAWIF's or the Coastal Zone color scanner are the more costly instruments and the ones that require more time to develop.

I wonder myself from the private side or university side why does it take so long. But if you look at the historic record a 5-year procurement and construction for MODIS–N is what it does these days for a fairly expensive instrument.

Senator GORE. Dr. MacDonald, do you have any comment on that?

Dr. MACDONALD. No. I just think that one can do these things more rapidly. They certainly are done in certain aspects of the military. I do not see why 5 years is somehow a magic number.

Dr. MOORE. One thing——

Senator GORE. Before you comment, Dr. Moore, I have tried to make the case that our national security is at stake here in ways similar to how it has been perceived to be at risk in the long military competition with the Soviet Union. It is not inappropriate, in my view, for the country as a whole to recalibrate the level of urgency being assigned to this, and surely there is some elasticity in the timeframes involved if we put greater emphasis on it.

I know you would like nothing better than that, but do you agree that we could speed some of these up?

Dr. MOORE. Two things. One, I think the instruments that we are talking about are not just technologically driven in terms of the schedule. It is the financial base. We have already seen that the President's 1992 budget was something like $181 million under for 1992, under what the 1991 budget showed for 1992. And then we saw the action of the House. I do not know what has happened

now, but those are not exactly going in the right direction toward bringing the program forward.

The second thing—and here I speak with some ignorance simply because I do not know what happens within the military world; it is not something that I work in or have any way in which to have that information available to me or to the payload panel—but assuming that it lives in the same physics as the rest of us, that there are certain basic principles that you are operating under when you are building a spectrometer, and if you want both a certain degree of spatial resolution and if you want to break the, I will use the word, light up into so many spectral bands, that is going to set certain dimensions for you.

I do not think that the NASA side of the house or the university side of the house is any less capable, and I do not think the aerospace contractors are different that are building a MODIS–N than the aerospace contractors that may be building something for the military. So, I do not think that there is any magic technological way in which we can get that same set of observations.

Now there may be ways of getting military observations where you are not looking for the same types of features that are quicker and cheaper, but I do not have that kind of information available to me. But if I want 36 channels of spectral information at such and such a spatial resolution, I think there are only a few designs that you are forced to.

Senator GORE. I am informed that the Senate is about to vote in another minute, and we have kept all of you throughout this long hearing.

Dr. Fisk, I want to especially thank you for staying for the follow-on panel and engaging in continued dialog on this. We are going to be coming back soon to look in great detail at the EOSDIS Program. We will have other hearings on Mission to Planet Earth; indeed, tomorrow the subcommittee will be looking at the NAS report on global warming and some of these questions will arise in that context as well.

But for now I would like to close the hearing by thanking all of you again for helping us on this thing.

[Whereupon, at 12:33 p.m., the subcommittee adjourned.]

APPENDIX

PREPARED STATEMENT OF MR. H. JAY MARGOLIS

On April 24, 1991, Dr. Leonard Fisk of NASA testified before the Senate Committee on Commerce, Science, and Transportation's Subcommittee on Science, Technology and Space, chaired by Senator Albert Gore, Jr. Senator Gore inadvertently "linked" the COSTAR proposal (concerning the Hubble Space Telescope's off-axis instruments) to Infinity Photo-Optical's Afocal Variation System (AVS) proposal [concerning the Hubble Space Telescope's on-axis Wide Field/Planetary Camera II (WFPC II) correction]. However, AVS is not-and never has been-an alternative to COSTAR- -as the question was put. In fact, AVS is totally unsuited to such use. Dr. Fisk essentially answered, that to his best knowledge, a committee of distinguished scientists had reviewed the Infinity AVS proposal and found it unworkable. To the best of Dr. Fisk's knowledge, that is probably correct. He is obliquely making reference to Infinity's scheduled participation at the Hubble Independent Optical Review Panel Meeting V (HIORP V). However, I dispute that a committee of distinguished scientists ever reviewed the Infinity proposal in fact, and certainly not with respect to the WFPC II correction. It is scientifically untenable to cavalierly reject a technology as "unworkable" that has never been given chance of explanation. No studies were ever undertaken by "the committee of distinguished scientists" as to the efficacy of AVS; no computer programs or optical bench analyses ever determined their "finding." Yet, AVS won two of the most prestigious technological awards: the Photonics Spectra "Circle of Excellence" (25 awards given) and the Research & Development "R&D 100" (100 awards given) in 1990. Out of 125 award-winning technologies, from two world-wide competitions, AVS emerged as the only one ever to win both accolades. Logically, any technology earning such recognition should also be worthy of more than a "brush-off." The record may someday show that NASA and its appointed panels may have suppressed the use of a technology that is decidedly in the National Interest. It is my opinion that the HIORP V Panel demonstrated inexcusably unscientific and unprofessional conduct.

I submit that there never was a true evaluation made of the Infinity AVS system as a correction for WFPC II. Moreover, at HIORP V (October 31, 1990), Infinity's distinguished optical consultant, Dr. Helmut Makowsky of Cologne, Germany and I were not permitted to continue our scheduled paper on the AVS system and its implications. Dr. Duncan Moore, HIORP V Chairman, halted our presentation, claiming we were "discussing a fix," when the meeting was to discuss the Hubble's "problems."

However, it was understood and agreed with Dr. John Wood of NASA before we came to HIORP V that we would be allowed to make our presentation, and we were placed on the Final Agenda in light of that understanding (as exchanged letters will prove). Therefore, this was a direct violation of the pre-meeting agreement. As a result, we are positive that whatever information we were allowed to give before we were stopped, was misinterpreted by NASA scientists and others at the meeting who may have thought that AVS was something they had invented earlier; namely a "prime focus corrector." Dr. A. Meinel even went so far as to draw out on his copy of our paper how AVS was "unworkable" and how "we (either Dr. Meinel or NASA—it was not clear) thought of that." Because he handed this "amended" and "corrected" drawing back to me, a copy—showing his "amendments" in his handwriting—is attached. Neither Dr. Makowsky nor I had any idea why Dr. Meinel drew-out what he did. What Dr. Meinel drew-out-and why-remained a mystery until April 1, 1991.

On April 1, 1991, I attended S.P.I.E.'s Orlando Conference on "Lessons Learned from the Hubble Space Telescope." There, I spoke with Dr. James Crocker of the Space Telescope Sciences Institute who made a similar statement to what Dr. Meinel had said, and referred me to the work of R. N. Wilson of ESA on "the subject." After checking Wilson's work, it was clear that AVS has no relation to prime focus correctors whatsoever. Prime focus correctors act on the spherical and other

aberrations directly; AVS does not: it only affects focus and, indirectly resets the telescope to nominal, in effect correcting spherical aberration thereby. Besides that, AVS is patented under U.S.# 4,988,173 with other U.S. and foreign applications allowed and pending. One specifically details the use of AVS on the Hubble Space Telescope. Since every AVS patent has been granted to date, I believe an AVS/Hubble patent will be issued shortly before or shortly after the scheduled space rescue of Hubble in 1993. I submit that AVS is unique Infinity Photo-Optical Company technology, and informed experts can and will verify this.

Months were wasted because of NASA's misunderstanding of, or refusal to hear about, AVS. Consequently, the JPL proposal gained an entrenched momentum without acknowledged opposition. The JPL fix was almost "preordained." Only weeks after Hubble's announced problem, Time and Newsweek (for example) detailed how Hubble's camera would be fixed by changing "a single quarter-sized mirror." Since that describes the JPL proposal even today, it is clear that NASA hardly entertained any other proposal. The HST Panel Strategy Report [1] of October 31, 1991 has more than nine combined pages devoted to "Two-mirror Correctors " and "SMARTSTAR" (what later became the COSTAR proposal); it has but one page (cryptic as it is) dealing with WFPC II. It is my opinion that JPL's proposal was "cast in stone" from the start. It may be that Infinity's proposal came as an unwanted surprise, all the more "rejectable" because it could work.

The "independent" panels that investigated Hubble were, in my view, anything but. Their proposed "solutions" also contradicted the Hubble's original mission and the bases upon which original funding was approved (details below). The "independent" panels' participants were too "collegially" related to the NASA scientists involved with Hubble. That is, many or most of the panels' members were either former students or professors of, or former contractors to, NASA personnel. Further, the "scientific circles" from which the panel members were selected were "ingrown" and "scientifically culture-bound." They all either adhered to, or believed in, the same prevailing scientific "paradigms" and theories (even if there might be disagreement within those theoretical limitations). In effect, the panels consisted of "believers" in a specific set of premises. Bordering on dogmatism, they were not prepared to hear from outside disciplines or experts outside their insular "paradigm." A truly independent panel would have been appointed by another Federal overseeing agency, composed of optical experts outside the "astronomy paradigm" as well as those within it, all of whom had no patronage from NASA in the past, and who were not "cultists" of the belief-structure that prevailed. In effect, the "independent" . panels were "rubber stamps" on preconceived methods. No matter how much those involved will deny that role, I maintain that that is what they did, in fact, do. Very possibly, they may still believe that they were involved in a constructive, deliberative process. I believe that they may still be deluding themselves that they played a "key role" at the panel meetings, because it is egotistically "expedient" to continue to do so. More likely, they were simply co-opted by those who had already decided upon what they wanted to do in any case. NASA recognized early-on that Public Relations would be essential "damage control" for Hubble. In my view, the panels were but another part of this charade. To my knowledge, contracts were awarded by NASA without any competitive bidding, without any competitive solutions. The panels' "recommendations" made that possible.

Had expert microscopical consultants, for example, been on the panels, they could have advised (as Infinity did) that the so-called p5 in the WFPC II were essentially long-distance microscopes. They could have attacked the corrective problem using the latest in microscopical technology. I believe microscopical experts would have designed a far different WFPC II than JPL did. Moreover, microscopical experts would not have dogmatically maintained the parameters and paradigm of mission expectations as the "independent" panels did. They could have been more objective, if only because they could see the problems from precisely the detached points of view that the panel members could not.

Further, the panels' recommendations were often contradictory. One example I can cite is the recommendation that Hubble be given an "aperture mask." This is a device that effectively reduces the light transmission, but cuts-out the potential defects by literally blocking them from ever forming as parts of the image. This was termed "a prudent option" in the HST Strategy Report-yet it is anything but "prudent." Historically, NASA argued that a 2.4 meter diameter telescope was essential to the mission. "Aperture masking" would have reduced the Hubble's effective aperture to c. 1.8 - 1.4 meters-hardly "prudent" in terms of the bases upon which Congress funded Hubble. That "aperture masking" could even be presented as "prudent" is historically contradictory [please see Robert W. Smith, The Space Telescope (New

[1] This material is being held in the subcommittee's files.

York : Cambridge University Press, 1989), pp. 149ff]. Essentially, had NASA chosen the "prudent alternative" of "aperture masking," it would have admitted that a much smaller, less-costly Hubble would have been possible and usable in the first place. Actually, it should be pointed-out that the original hopes were for a 3.0 meter Hubble. (AVS technology applied to WFPC II would so increase the light transmission and quality, that it might equal a conventionally-designed WFPC with a 3.0 meter instrument. In effect, Infinity's WFPC II proposal could substantially offer the taxpayers much more for their money than originally mandated.)

At the very least, NASA did not understand AVS technology. This is evident by their description of the Hubble's problem as "spherical aberration." Actually, the Hubble does not have "spherical aberration;" it produces "spherical aberration" as a by-product of a focusing error. Anyone familiar with how AVS works would define the Hubble's problem in that way, and not simply as "spherical aberration." NASA "attacked" the Hubble correction with the understandings and resources on- hand. Those would have dictated that the problem only be solved by correcting "spherical aberration." This is another example of how "culture-bound" and insular their approach was. Consequently, the very fact that NASA stated the Hubble's problem as "spherical aberration" evidences their unfamiliarity with AVS, not their anticipation of it.

Since initiating contacts with NASA, AVS has been shown to other experts and has been tested by them. Dr. Fisk stated that it was his belief that AVS was "unworkable." However, a copy of a letter[1] written by Dr. Robert A. Kamper, Director of the National Institute of Standards and Technology's Boulder Laboratories to Senator Timothy E. Wirth is attached which clearly implies quite otherwise. I would appreciate if it could be entered into the record. To quote Dr. Kamper: "We saw no obvious objection in principle to Mr. Margolis' proposal. * * *"

One major NASA contractor has tested AVS and is seriously considering its use in a forthcoming project-very related to how it could be used in Hubble. In effect, AVS has been demonstrated to be a viable telescopical focusing system which functions independent of the image-forming optics. This implies that it could be used to correct Hubble.

In consequence, I have prepared an analytical comparison[1] of AVS with NASA Jet Propulsion Laboratory's proposal for WFPC II's correction. I would appreciate if it would also be entered into the record.

Unless a dramatic effort is undertaken promptly, there will be no opportunity to incorporate AVS into the Hubble's WFPC II correction in time to meet the 1993 scheduled space rescue mission. Further, I advocate that an investigation should be made into the methods and means by which NASA determined its corrective approaches for Hubble and how and why contracts were awarded. I also call for a direct comparison of AVS with JPL's proposed fix, scientifically conducted by a truly independent agency. Lacking these investigations and efforts, I predict that if the present JPL proposal is used, there will be a WFPC II failure in 1993—or whenever the space rescue mission is finally attempted.

Recently, NASA Goddard Spaceflight Center contacted Infinity Photo-Optical to request delivery information on an AVS module in order to test the spherical aberration of a simulated Hubble light beam. Infinity provided this information and granted NASA a limited license to use AVS in making such a determination, should they care to do so. No other license or rights were extended or implied. To date, we have not heard from NASA as to whether or not they would like an AVS module for experimental determinations.

To the best of my knowledge, this statement is factual, true and correct. Opinions expressed are the result of over twenty-five years of experience in the optical field, several patents and internationally-recognized awards for optical innovations. Neither I, nor Infinity Photoptical have any connection whatsoever to NASA or the Hubble Space Telescope as of this date.

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